Technical Note N-633

GROUND ROD METALS - RESULTS OF TWO ONE-YEAR TESTS

BY

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15 October 1964

U. S. NAVAL CIVIL ENGINEERING LABORATORY
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Y-F015-99-01-031

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ABSTRACT

The U. S. Naval Civil Engineering Laboratory has been investigating various metals now in use as ground rods, and metals which might be acceptable substitutes. NCEL cooperated with the National Association of Corrosion Engineers by installing a series of test rods at the Laboratory. A smaller set was installed at the Naval Air Station, Point Mugu, California as a short-term test. Test results are given for the first group of rods from the NCEL site and for the set from Point Mugu. It is recommended that corrosion-resistant iron alloys be authorized for use in grounding systems.

INTRODUCTION

Power transformer stations radar installations and radio stations all require extensive buried grounding networks The metal most commonly used for this purpose is bare copper as a solid rod or wire, or as a coating or cladding on a stronger base metal such as steel. A serious problem arises when extensive amounts of copper are buried in proximity to a less noble (less corrosion-resistant) metal: corrosion of the other metal is accelerated and the second metal eventually fails to perform its primary function. This is particularly true when the copper is bonded electrically to another metal, as in a steel-framed or steel-covered building where parts are buried in the earth, a copper grounding network is connected to an undergrounding piping system--a common practice in industry.[1]

The Bureau of Yards and Docks authorized the Naval Civil Engineering Laboratory to investigate several metals which might serve as ground rods. An economically acceptable substitute for copper would be desirable, if compatible with steels or other buried metals, as would be alternates for emergency situations when copper was unavailable. The Laboratory then arranged to cooperate with the National Association of Corrosion Engineers (NACE) in its "Driven Ground Rod Test Program."

This report presents NCEL's test program, a description of the test sites, and details relative to installation and removal of test rods. Results are given for the test rods removed to-date.

TEST PROGRAM

Two sites were chosen, one at NCEL and the other at Point Mugu. Rods of various metals were obtained, weighed, and driven into the ground in three groups at NCEL A group of rods was to be removed after 1 year, a second group after 3 years, and a third after 7 years. In a short-term test at Point Mugu, a single group of rods was installed for 1 year only. After removal, the rods were to be examined, cleaned, and weighed. The loss and rate of corrosion would be determined.

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1. J. D. Gheshquiere. "Cathodic Protection and Zinc Grounding in Industrial Plant Construction," Corrosion (March 1961), p. 149t. (121).

Test Sites

NCEL. At this test site, at the southeast corner of the main Laboratory compound, the NACE test program was followed, with minor modifications. Figures 1 and 2 show the site in relation to its surroundings. It is approximately 20 feet wide and 200 feet long; two reference electrodes were permanently installed at 50 and 100 feet from the nearest edge of the site, on a line perpendicular to the length of the site at the site's center. The site parallels the south boundary fence; the first row of test rods is 6 feet from the fence.

Preliminary borings indicated that the subsoil at the site is a natural deposit of sand and gravel. Fill, placed some years previous to this test program, consisted of 5 feet of sand and gravel, hydraulically placed, followed by a 3-foot layer of crushed sandstone to grade. The average resistivity of the 8-foot fill is about 1400 ohm-centimeters.

Point Mugu. This Naval Air Station site was selected for a short-term test because it was believed that the soil would accelerate results. The location (Figures 3 and 4) is sometimes covered by water at high tide and during the rainy season. The site is about 20 feet wide and 70 feet long. Two reference electrodes were located 50 and 100 feet from one edge of the site, on a line perpendicular to the length of the site at the site's center.

The top layer of soil, a fine, silt-like material, is 28 inches deep. Below that is a 2-inch-thick layer of sand with a few thin layers of silt, then sand again for 6 inches. At this 36-inch depth the color of the sand changes from tan to blue-grey, and it seems slightly finer. Below this depth, the sand continues unchanged indefinitely, except for the addition of marine shells below 4 feet. The average resistivity of the soil to an 8-foot depth is about 46 ohm-centimeters.

Rod Groups

Each group of rods consists of two subgroups. The first subgroup consists of single rods of all the metals used in the test. For the second subgroup, a rod of each metal was coupled to one or two mild steel rods. The coupled rods, by their dissimilarity, formed the anodes and cathodes of galvanic cells. The number of steel rods coupled to the other metals was varied to compare the effect of different anode-to-cathode area ratios.

Test Rods

Thirty-one rods of eight different metal systems are included in each group (Figure 5). The rods are nominally 5/8 inch in diameter by 8 feet long. They are pointed on one end to facilitate driving and chamfered on the other end to minimize mushrooming when driven. The metal systemsare mild steel, galvanized steel, Ni-Resist, Type 302 stainless steel, copperclad steel, high-purity zinc, AZ31B magnesium alloy, and No. 6061-T6 aluminum alloy. Single rods of mild steel were coupled to single rods of the other seven metal systems, to provide the different anode-to-cathode area ratios mentioned above, two mild steel rods were coupled to single rods of copperclad steel, magnesium, and zinc.

Data

All rods were weighed before installation. As each group is removed from the ground, the individual rods will be freed of corrosion products, reweighed, and their corrosion losses determined. At the time of installation, each rod's potential to a copper sulfate half-cell and its resistance to earth were determined. The same data was obtained for pairs of mild steel rods as soon as they were connected to each other. The potential to a copper sulfate half-cell, the resistance to earth, and the current flow were determined for all couples as soon as they were formed. The same data were obtained on a monthly basis thereafter, as conditions permitted. Also recorded during the test period were the amount of rainfall and other data that might be considered pertinent as a result of further investigations.

Significance of Types of Measurements

Although this study was to determine how well different metals might function if used in buried grounding systems, it was also necessary to learn how these metals would affect or be affected by other buried metallic structures.

The in-place determination of the corrosion of buried metallic structures. is almost impossible without a further disturbance of the environment. However, certain methods exist which give an indication of the rate at which a metal is corroding. One method is to determine the potential of the structure relative to a particular reference electrode, such as a copper sulfate half-cell. With steel, for example, a potential of less than 850 millivolts negative to the half-cell is

generally taken as an indication of the existence of a corrosion problem. A potential between 850 and 1000 millivolts negative to the half-cell indicates that the structure is not undergoing significant corrosion. A potential difference greater than 1000 millivolts (usually with the structure under some form of cathodic protection) often is accompanied by gas formation, which may have a harmful effect on the structure.

A second method is to measure the current flow between parts of the structure. Where galvanic corrosion occurs a current path is set up between two or more parts of the structure; as the current flows, one part corrodes at a rate proportional to the magnitude of the current. If this method is to be used, a shunt may be installed in the current path for ease in measuring current flow. An alternative is to establish one or more locations where the current flow can be interrupted, and to periodically measure current flow at such locations.

A third method, long used in checking electrical grounding systems, is to determine the grounding metal's resistance to earth. A build-up of corrosion products around the rod may be indicated by an increase in the resistance. Soluble salts are often placed around a ground rod to increase the conductivity of the soil and thus lower its resistance; if the resistance to earth increases, this could indicate that the salts are being leached away and replenishment is necessary. Soil moisture affects the functioning of the ground; if resistance increases, this indicate a decrease in moisture content (perhaps a lowering of the water table), making necessary a longer ground rod to reach a moist soil stratum.

PROCEDURE

Installation

At NCEL, rods were installed in a rectangular pattern (Figure 2) on 6-foot centers and arranged as shown in Figure 6. After they had been started with a sledge hammer, the rods were driven with an air hammer with a special driving head (Figure 7). A 5/8-inch-diameter steel rod was used to make pilot holes for the aluminum, magnesium, and Ni-Resist rods. Large stones and the hard soil surface could cause the Ni-Resist rods to fracture and the other two materials to mushroom abnormally. A slightly larger rod was used in making pilot holes for the easily bent zinc rods; when the rods were inserted, the holes were filled with fine sand. The installation was completed on 3 August 1962.

The pattern of the 1-year group at the NCEL site was followed at the Mugu site, as noted in Figure 6. The actual installation at Mugu was much simpler, however, since the rods could be pushed into the ground by hand until the sand layer was reached. The rods were driven the rest of the way with light hammer (Figure 8). A simple driving head was used on the softer metals to minimize mushrooming. No pilot holes were needed, and the Mugu installation was completed on 10 August 1962.

Removal

The 1-year group of test rods at NCEL was removed from the ground 13 months after installation. One end of a "come-along" was attached to a projecting rod stub and the other end to the blade of a forklift. The blade was raised, pulling the test rod from the earth. Most of the rods were removed with no difficulty, but the two magnesium rods coupled to mild steel rods broke a few inches below the ground surface. Small holes were dug beside these rods so the rest could be pulled out. The single magnesium rod came out easily.

Several of the pulled rods were bent, which must have happened during installation. This probably was caused by one of the large stones below the soil surface. Figure 9 shows four of the bent rods; the most severely bent was copperclad steel.

During a routine inspection and measurement 2 months after the Mugu rods were installed, it was found that the coupled magnesium rods had corroded to complete separation at ground level. By digging a narrow hole beside the magnesium rods it was possible to obtain portions of the columns of corrosion product. The steel rods to which the magnesium had been coupled were also removed at this time.

Four months after installation, the single magnesium rod had corroded through at about 3 inches below ground level. An additional section of the buried portion of this rod was also obtained. Figure 10 shows the recovered portions of all three magnesium rods.

About 13 months after installation, the rest of the Mugu rods were removed. They were twisted in place to loosen them and then easily pulled up by hand. However, the coupled aluminum rod had corroded through at ground level, so it was necessary to uncover it for a few inches for gripping and pulling.

Cleaning

When the test rods were removed, dirt and loosely-adhering corrosion products were brushed off with a stiff-bristle scrub brush. The remaining corrosion products were removed by a combination of chemical cleaning and scrubbing (Table I).

Table I. Cleaning Procedures

Test Rod	Chemical	Method [1]
Mild Steel	10% Ammonium Citrate (heated to 120F)	Rod immersed and scrubbed
Ni-Resist	10% Ammonium Citrate (heated to 120F)	Rod immersed and scrubbed
Copperclad Steel	18% Hydrochloric Acid	Acid swabbed on rod
Galvanized Steel	10% Ammonium Chloride	Rod immersed and scrubbed lightly
Zinc	10% Ammonium Chloride	Rod immersed and scrubbed lightly
Stainless Steel	Concentrated Nitric Acid	Acid swabbed on rod
Aluminum	Concentrated Nitric Acid	Acid swabbed on rod
Magnesium	6.5% Chromic Acid	Rod immersed

[1] After cleaning, all rods were rinsed with deionized water

RESULTS

NCEL Site

The numerical values of the potential, resistance-to-earth, and current flow measurements made during the test period are given in Table I-A (Appendix A).

Potentials. The potentials of the single rods (Figure 1-B, Appendix B.) were relatively constant during the test period, with individual rods varying a maximum of 145 millivolts (mv). There was one exception; the galvanized steel rod varied approximately 770 mv. Almost all of this change occurred during the rainy season, as can be seen by comparing Figure 1-B with 2-B.

The potentials of four of the ten couples (Figure 3-B) were quite close and relatively constant. These were mild steel rods coupled with copper (two couples), Ni-Resist, and stainless steel. In each of these cases the mild steel is functioning as a sacrificial anode.

The potential of the aluminum couple was even more constant than these, but was at a slightly higher value.[1] The magnesium couples showed a rapid increase in potential during the first month, and a gradual decrease from then on. The magnesium - single-steel couple showed a rapid decrease in potential after 9-1/2 months. This continued until the last three weeks of the test period, when the potential appeared to be increasing again.

The potentials of the zinc couples increased somewhat during the first month and then became relatively stable for 4 months. Both couples then showed an increase over the next month, followed by a decrease. The zinc - single-steel couple showed a slight decrease for 3 months, followed by an increase. The zinc - double-steel couple showed a greater decrease for 4 months, followed by an increase to almost the same final value as the zinc - single-steel couple. The galvanized rod was stable for two weeks, and then rapidly decreased in potential over the next three months. Its potential became almost the same as that of the four couples mentioned earlier, which it paralleled for the remainder of the test.

Current. Data on current flow in the various couples have generally shown a stable or slightly increasing current for the first month, followed by a general decrease of varying magnitude (Figure 4-B). The greatest ranges in current flow were shown by the galvanized couple (25 milliamperes) and the magnesium couples (52 and 54 ma.).

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[1] All potential values are negative with respect to a copper sulfate half-cell. A higher value of potential, or an increase in potential means more negative with respect to the half-cell.

Resistance. The resistance to earth of single and coupled rods follow a somewhat similar pattern after the first month (Figures 5-B and 6-B). The resistances of the single rods (Figure 5-B) were, in general, about level for the first month, followed by a general increase until the sixth month. One rod (mild steel) showed an abrupt increase in resistance during the first two weeks, followed by an almost equally abrupt decrease, leveling off at a value higher than it had initially. Another rod (galvanized) increased rather rapidly in resistance for 5 months after installation; its resistance then leveled off, and it tended to follow the balance of the rods.

During the 3-month period following the January readings, resistance decreased markedly, and then increased to about pre-decrease level. This occurrence corresponds to the main portion of the rainly season. After the end of June all rods exhibited a pronounced decrease in resistance. This could not be related to rainfall since there was an insignificant amount of rain until just at the end of the term of this study.

The resistance to earth of coupled rods (Figure 6-B) generally decreased during the first month and then increased steadily for 4 more months. As with the single rods, the resistances of most couples dropped fairly sharply during the rainly season, and all showed a strong decrease in resistance during the last 2 months. Two exceptions were (1) the magnesium - double-steel couple, which had a 50 percent increase in resistance during the first 2 weeks and then returned to a value below the original, and (2) the galvanized rod couple, which almost doubled in resistance during November but dropped back to about the same resistance as before the increase. These two anomalies might be attributed to instrument error or inadequate contact. Neither of these couples, plus the copper - single-steel couple, showed a significant drop during the rainy season.

Weight Losses. The weight losses of the various NCEL rods are given in Table III-A, along with calculated corrosion rates. For the single rods, stainless steel had the least percent weight loss, followed in increasing order by copperclad steel, Ni-Resist, aluminum, zinc, galvanized steel, mild steel, and magnesium.

The affect produced by coupling the various metals to one or more mild steel rods is found by comparing the corrosion rates for the single rods to the couples. Coupling to copperclad steel resulted in an 88 percent increase in the corrosion rate for a mild steel rod; two mild steel rods produced a 45 percent average increase in corrosion rate per rod. The corrosion rate for the copperclad steel was reduced by 27 percent and 32 percent by coupling to one and two mild steel rods, respectively.

Coupling Ni-Resist to mild steel produced corrosion rate reductions for both rods of 62 percent and 6 percent, respectively; with stainless steel in place of Ni-Resist, the respective reductions were 69 percent and 1.2 percent. Galvanized steel caused a 52 percent rate reduction for the mild steel; the corrosion rate for the galvanized rod was increased to almost 2-1/2 times that of an uncoupled rod. The corrosion rate for the mild steel was reduced 60 to 67 percent by aluminum, magnesium, and zinc, whose rates were increased to 8, 8.9, and 5.7 times those for uncoupled rods. The corrosion rate for magnesium was increased to 11 times that for an uncoupled rod when two mild steel rods were used in the couple; the rates for the mild steel rods were reduced an average of 70 percent. The corrosion rate for the zinc rod, when coupled to two mild steel rods, was increased to 7 times that for a single zinc rod; the rates for the steel rods were reduced by 67 percent.

Mugu Site

The numerical values of the potential, resistance-to-earth, and current flow measurements made during the test period are given in Table II-A.

Potentials. The potentials of single rods at the Mugu site were fairly constant, with the variations of individual potentials limited to from 100 mv up to 300 mv (Figure 7-B). An obvious exception was the potential of the galvanized rod, which in 8 months decreased about 140 mv from its original value, and then suddenly decreased an additional 520 mv, subsequently increased 490 mv and finally decreased 330 mv. In the last 5 months of the test period, the potential of the steel rod decreased 270 mv; that of the aluminum rod decreased 260 mv in the last month of the test period.

The potentials of four couples - mild steel coupled to copper (two couples), Ni-Resist, and stainless steel - remained very close during the test period; almost all were within the range of 650 mv to 700 mv (both negative with respect to the copper sulfate half-cell). In Figure 8-B, these four are shown as an average on the regular scale an individually on an expanded scale. The potential of the aluminum couple was equally constant, but 150 mv higher in value. The potential of the two zinc couples increased slightly during the first 2 weeks, but decreased almost to the original values within the first month. The potentials remained essentially constant for the remainder of the test period, except for one reading that showed an unaccountable decrease in potential of the zinc - double-steel couple. The potential of the galvanized rod couple followed those of the zinc couples for 2 months, and decreased over the next 3 months into the -700 mv to -750 mv range, closely paralleling the potentials of the group of four couples mentioned above. The two magnesium rods coupled to mild steel were almost completely corroded away in less than 2 months, but during the first month the two magnesium couples averaged 1392 mv.

Currents. Current flow in couples was quite irregular over a range of 0.2 to 10 ma. (Figure 9-B). Exceptions were the currents in the zinc couples and the galvanized couple. Initial values were between 47 and 62.5 ma; these decreased rapidly during the first three months to averages of about 7 and 4.3 ma for the zinc couples and 0.7 ma for the galvanized couple. From those points the current in the zinc - double-steel couple averaged about the same, and the average current in the zinc - single-steel couple decreased from 4.3 to 2.5 ma. The current in the galvanized couple averaged less than 1 ma for 8 months but then increased from 0.42 to 2.06 ma, followed by a decrease to 1.16 ma on the date the rods were removed. Currents flowing in the two magnesium couples were:

Magnesium coupled to	Aug 10 (ma)	Aug 16 (ma)	Sept 7 (ma)
Single steel rod	605	1120	470
Two steel rods	789	1120	420

Resistance. The resistance to earth of four single rods (copperclad, aluminum, Ni-Resist, and stainless steel) were rather irregular but lay within a narrow range from 0.34 to 0.70 ohms (Figure 10-B). The resistance of mild steel rod fell in the same range for 9 months, and then increased to 10.5 ohms; from that point it dropped to about 6 ohms for 2 months and then to 0.72 ohms on the day the rods were removed. The resistance of the magnesium rod increased to 29 ohms during the third month, when it was remove. The resistance of the galvanized steel rod was less than 1 ohm for 9 months, but increased to 95 ohms at the tenth month. Two weeks later it dropped to about 30 ohms, to 0.63 ohm after 5 more weeks, and increased to 1.12 ohms on the date the rods were removed.

The resistance of eight couples varied between 0.25 and 0.80 ohm during the first 6 months, with an increasing degree of variation (Figure 11-B). Five couples (the aluminum, galvanized steel, and Ni-Resist, and the two copper) had at least one value beyond 1 ohm. The resistance of the galvanized steel couple was such that a stable reading could not be obtained during the last 3 months; it was about 28 ohms, but the instrument needle could not be stabilized.

Weight Losses. The weight losses for the group of rods installed at Point Mugu are given in Table III-A. The single rods, in order of increasing percent loss are stainless steel, aluminum, Ni-Resist, copperclad steel, zinc, mild steel, galvanized steel, and magnesium.

When copperclad steel was coupled to a single mild steel rod, the corrosion rate for the mild steel increased 26 percent, and that for the copperclad steel decreased 68 percent. With two mild steel rods instead of one, the copperclad rate decreased 73 percent, and the rates for the steel rods increased on an average of 52 percent. When they were coupled, Ni-Resist's rate decreased 72 percent, and mild steel's rate increased 65 percent. The corrosion rate of stainless steel was unaffected by coupling to mild steel, but the latter's rate increased 46 percent. A galvanized rod's rate increased 6 percent; the mild steel rod to which it was coupled dropped 36 percent. The rates for aluminum, magnesium, and zinc coupled to mild steel rods were increased 4.8, 1.3, and 2.6 times, respectively; the mild steel rods to which they were coupled dropped 28 percent, 38 percent, and 47 percent. Coupling magnesium to two mild steel rods yielded a 31 percent increase in its corrosion rate; the rates for two steel rods were reduced an average of 52 percent. The zinc rod's rate was increased to four times that of the uncoupled rod when coupled to two mild steel rods; their rates were reduced an average of nearly 6 percent. However, one of the steel rods corroded more than if it had not been coupled.

DISCUSSION

Three factors determine the acceptability of a grounding system: (1) its resistance to earth; (2) its effect on the corrosion rate of other buried metals; and (3) its electrical conductivity. These factors depend on several others, such as moisture in the soil, particle size, dissolved solids, degree of aeration, the grounding requirements of a structure, properties directly related to the metal in the grounding system and any other buried metal which might be involved.

Based on the resistance-to-earth data for the single rods at the NCEL site, stainless steel is the best metal for use in a grounding system. Next best are aluminum, magnesium, galvanized steel, mild steel, copperclad steel, zinc, and Ni-Resist. Resistance data from the Mugu site indicate copperclad steel as the preferred rod, followed by Ni-Resist, stainless steel, mild steel, aluminum, zinc, galvanized steel, and magnesium, in that order. The data indicate that if properly used, any of these rods would be acceptable, with the possible exception of magnesium and zinc. As ground rods, they corrode too rapidly in providing cathodic protection to other metals. Mild steel and galvanized steel ground rods generally should have cathodic protection (see Part M, TP-Pw-30,[1] where magnesium and zinc are indicated as sacrificial anode material for protecting zinc-coated steel). Magnesium was installed to protect mild steel ground rods at Bethlehem Steel's Fairless Works near Morristown, Pennsylvania.[2]

1. Corrosion Prevention. Part M of NavDocks TP-Pw-30, Maintenance and Operation of Public Works and Public Utilities. p. M331.
2. Coleman, W. E., and H. G. Frostick. "Electrical Grounding and Cathodic Protection at the Fairless Works," Paper No. 55-110, presented at the AIEE Winter General Meeting (31 Jan - 5 Feb 1955) New York.

Current flow measurements indicated that the mild steel rods were serving as sacrificial anodes for copperclad steel, Ni-Resist, and stainless steel, and as a cathode for aluminum, magnesium, and zinc. Potential measurements indicated a low potential for couples incorporating the first group of metals, and an acceptably or excessively high potential for couples with the other metals except aluminum. The potential of a couple incorporating aluminum (at the NCEL site) was lower than that generally acceptable; however, the corresponding couple at Point Mugu was in the accepted range.

The effects on the corrosion of mild steel brought about by coupling the steel to other metals is most clearly demonstrated by the changes in weight of various steel rods. These weight changes are shown in Table III-A. The single rods of mild steel, Ni-Resist, stainless steel, and aluminum corroded almost twice as much as their counterparts at the Mugu site. The galvanized rod at NCEL lost only half as much as the one installed at Mugu. This might have been caused by difference in soil texture and moisture. Also, imperfections in the galvanized coating could have exposed the steel core. The galvanized coating would then be a sacrificial anode to the exposed core and would be consumed at an ever-increasing rate to protect the exposed area.

The copperclad steel rods installed singly lost about the same weight at both locations. This loss was due to corrosion of the steel core at the lower end of each rod, with the steel providing protection to the copper sheath.

The effects of coupling the various metals to mild steel rods were consistent. The corrosion rate of the coupled copperclad rod at NCEL was only 73 percent of the rate of a single rod; at Mugu, the rate of the coupled rod was only 32 percent of the single rod's rate. The corrosion rate of the mild steel rod in the NCEL couple was about 90 percent more than an uncoupled rod, but at Mugu it was only 25 percent as much. At Mugu, the steel provided more than twice the protection to the copper rod with less than one-third the metal loss. A lower earth resistivity at Mugu may have caused less metal to be consumed to overcome the couple's total resistance and provide the indicated protection.

At NCEL, Ni-Resist corrosion rate was reduced to four-tenths that of a single rod by coupling to a mild steel rod, with a decrease of 6 percent in the mild steel rod's corrosion. At Mugu, the Ni-Resist rod's corrosion rate dropped to three-tenths that of a single rod but the mild steel's rate was increased by 65 percent. The Type 302 stainless steel rod's rate was decreased to about three-tenths that of a single rod when it was coupled to a mild steel rod at NCEL, with only a slight decrease of the mild steel rod's rate. At Mugu the stainless steel rod's rate was essentially unaffected by coupling to mild steel, but at a 46 percent increase of

its mild steel partner's rate. Some passivation may have occurred at NCEL which could not at Mugu because of the difference in soil and moisture.

The galvanized rod at NCEL decreased by 50 percent the corrosion rate of the mild steel rod to which it was coupled, but at the cost of a corrosion rate equal to 2-1/2 times the rate of an uncoupled galvanized rod. At Mugu a similar couple showed a 36 percent reduction in the corrosion rate of the mild steel and only a 6 percent increase of the galvanized rod's rate. The galvanized rod shows little evidence of localized corrosion, indicating a lack of imperfections in the galvanized coating.

The 60 to 67 percent reduction in the corrosion of mild steel rods brought about by coupling to aluminum, magnesium, and zinc at the expense of their own corrosion rates is to be expected. It has already been mentioned that magnesium and zinc will corrode to provide cathodic protection to many other metals, and the same is true for aluminum. The high potentials evidenced by both zinc and magnesium at Mugu, and by magnesium at NCEL are evidences of over-protection.

Doubling the number of mild steel rods in couples with copperclad steel, magnesium, and zinc produced results that might be predicted. The corrosion of the copperclad rod was decreased at both sites, and the rates for magnesium and zinc were increased at both. The effect on the mild steel rods was not uniform however. At NCEL, corrosion of the steel rods coupled to copper increased an average of 45 percent, which means that the total loss of metal was about the same for both couples. At Mugu, the average rate for the double-steel couple was twice that of the steel in a single-steel couple. Nothing was observed to account for this difference.

With magnesium, the average reduction in corrosion of two steel rods was the same as for single-rod couples. With zinc, the same can be said at NCEL, but at Mugu the average reduction in corrosion rate for the steel rods was 6 percent, with one of the rods having a 17 percent increase in corrosion rate and the other a 28 percent reduction. When the rods were removed, an appreciable amount of moisture and rust was found under the plastic insulation covering the connections at the steel rods. Evidently the connection to the zinc rod was broken by moisture and rust, and then one rod became a sacrificial anode to protect the other rod.

CONCLUSIONS

The overall view of the results of the two 1-year tests leads to the following conclusions:

1. Stainless steel and Ni-Resist are preferably to copperclad steel in these two locations.

2. Mild steel and galvanized steel would be acceptable if an adequate cathodic protection system were incorporated into the grounding system.

3. Copperclad steel would be acceptable if not connected to other buried metals.

4. Aluminum, magnesium, and zinc are not acceptable.

RECOMMENDATIONS

It is recommended that corrosion-resistant iron alloys be authorized for use in grounding systems.

ACKNOWLEDGMENTS

Many NCEL staff members assisted in this study. The Trades Department made and installed the test rods. Mr. Fred Reinhart, Materials Division, suggested several of the methods used in cleaning the test rods.

The Commander, Naval Air Station, Point Mugu, gave permission to conduct a 1-year test, and Mr. William O'Kane, Director, Planning Division, PMR Public Works, assisted in selecting the test site.

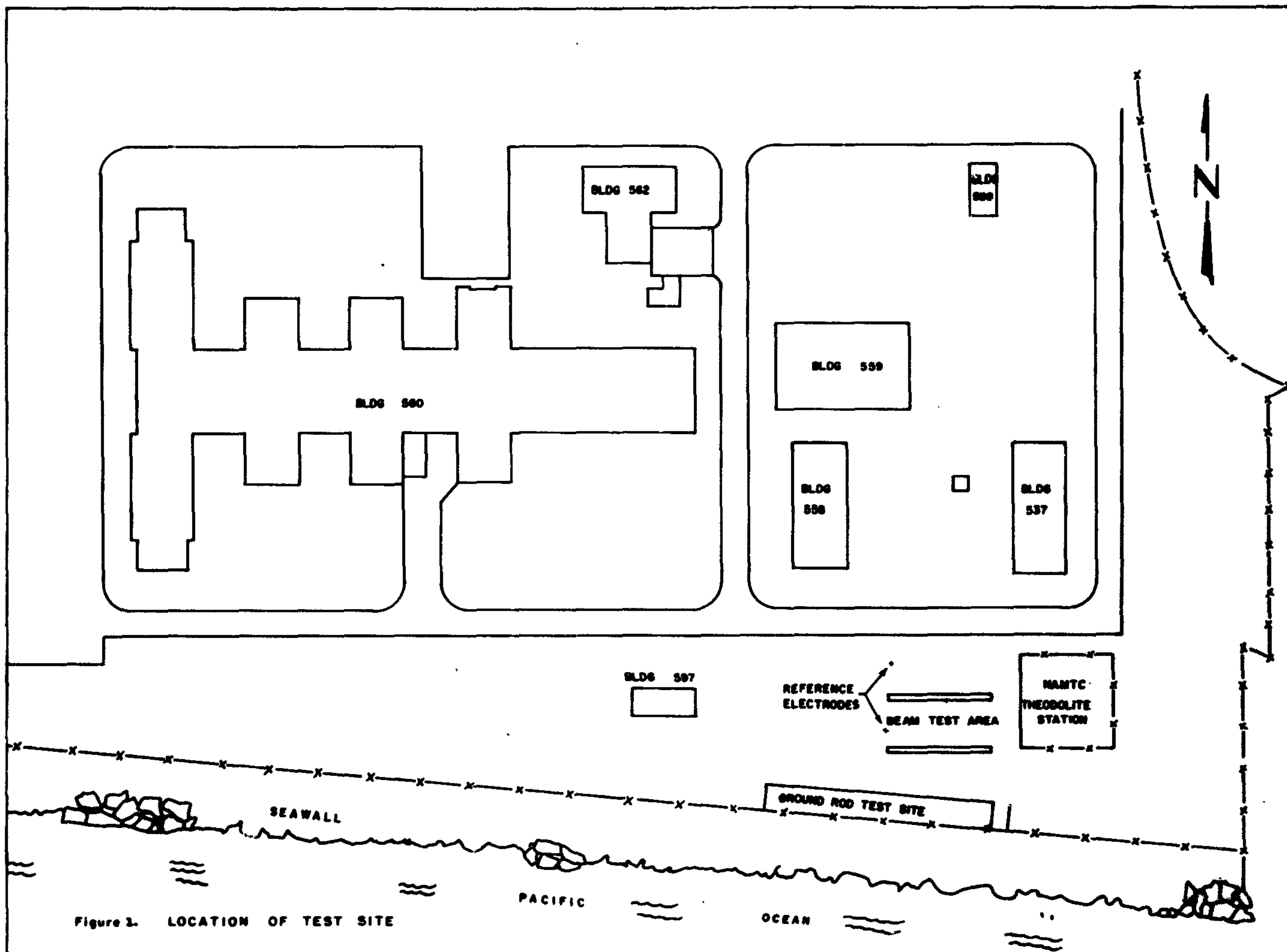


Figure 1. LOCATION OF TEST SITE

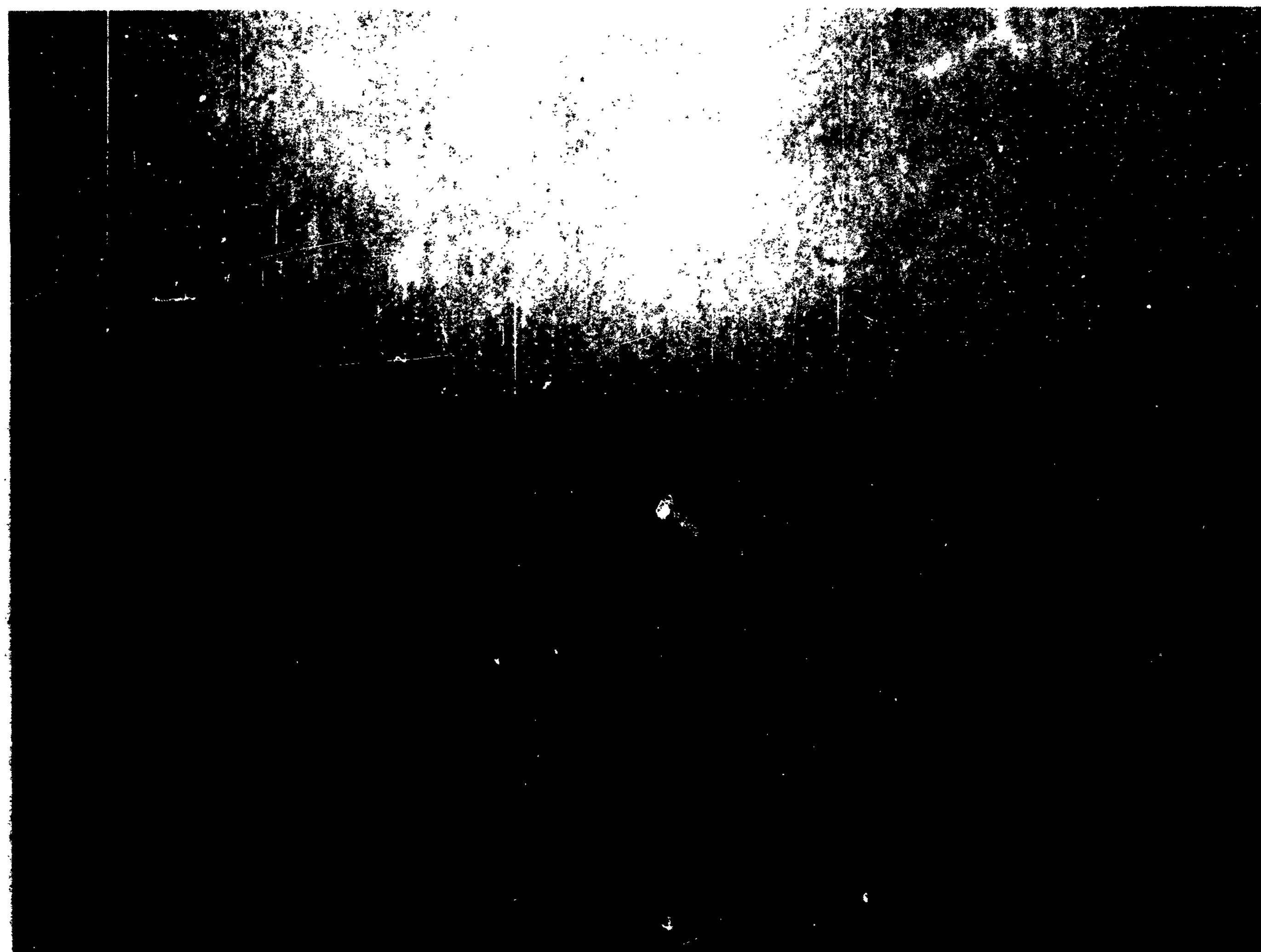


Figure 2. Ground rod test site. Breakwater and boundary fence at left, test area center foreground, neutron generator facility center rear, beam test site at right.

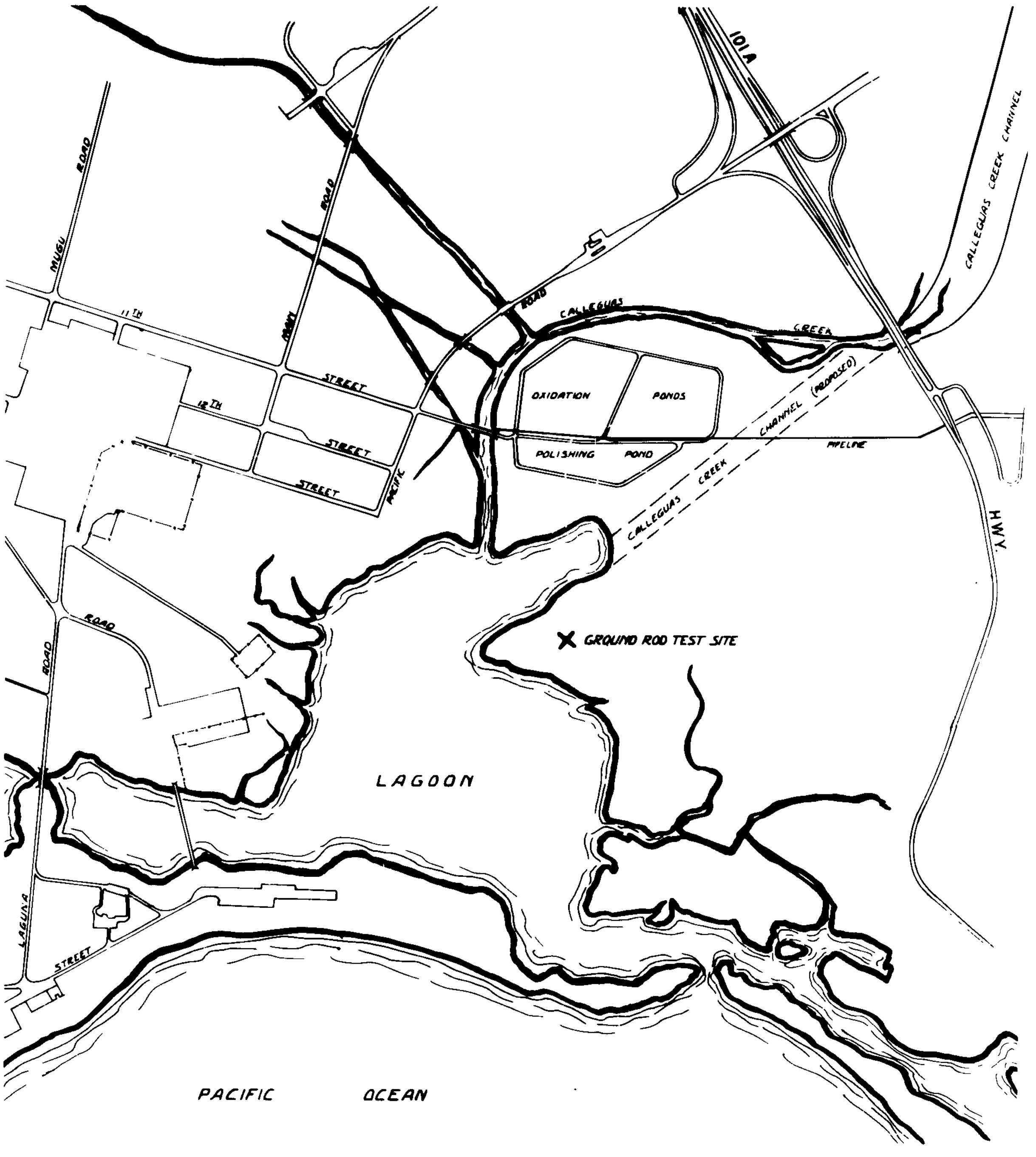


FIGURE 3. GROUND ROD TEST SITE — POINT MUGU

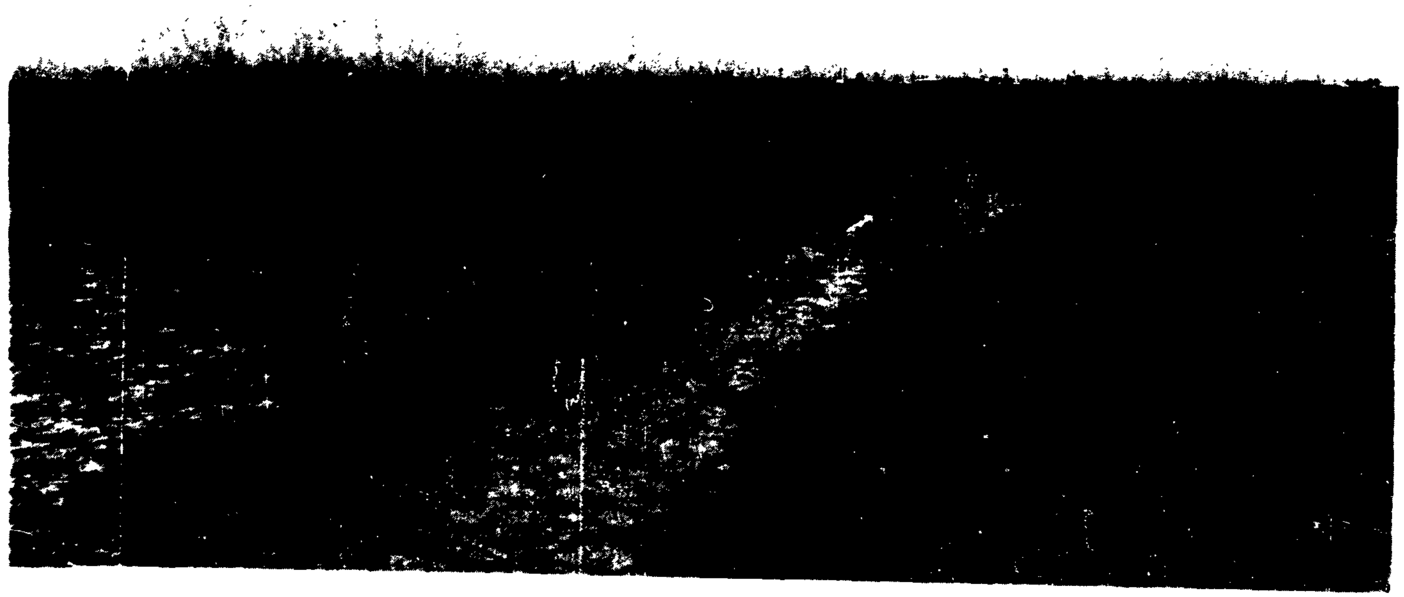


Figure 4. Ground rod test site, Point Mugu.

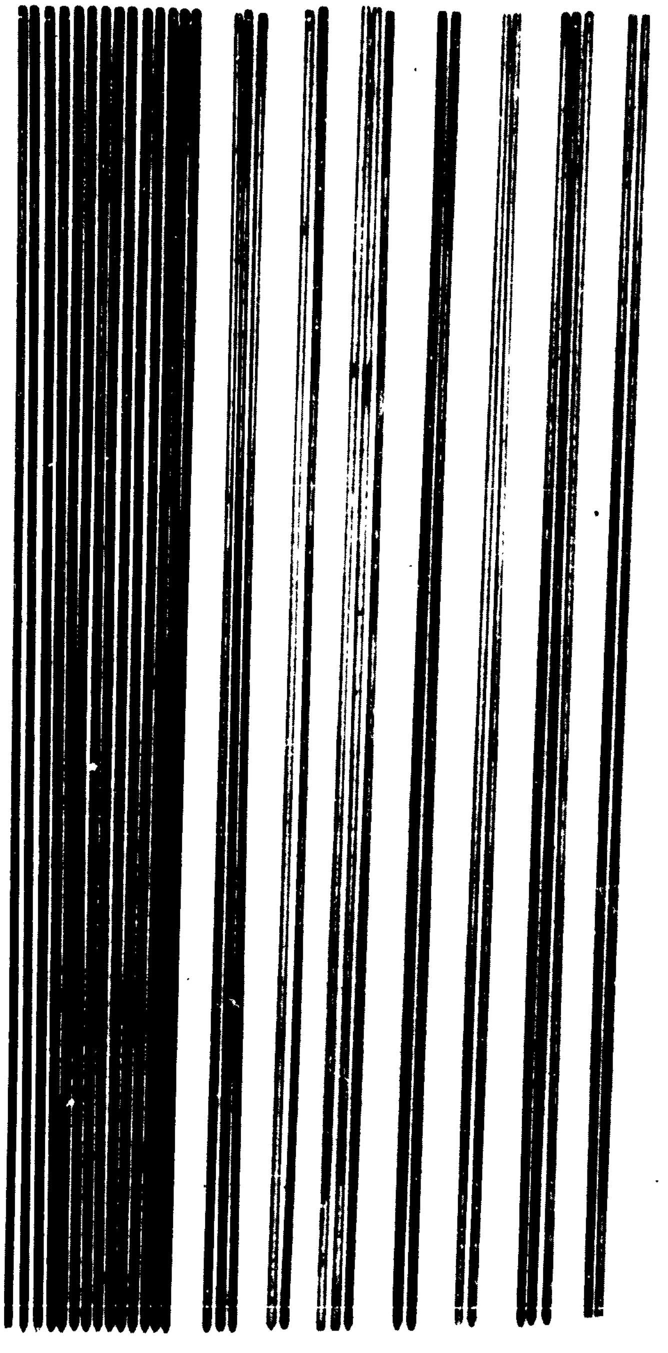
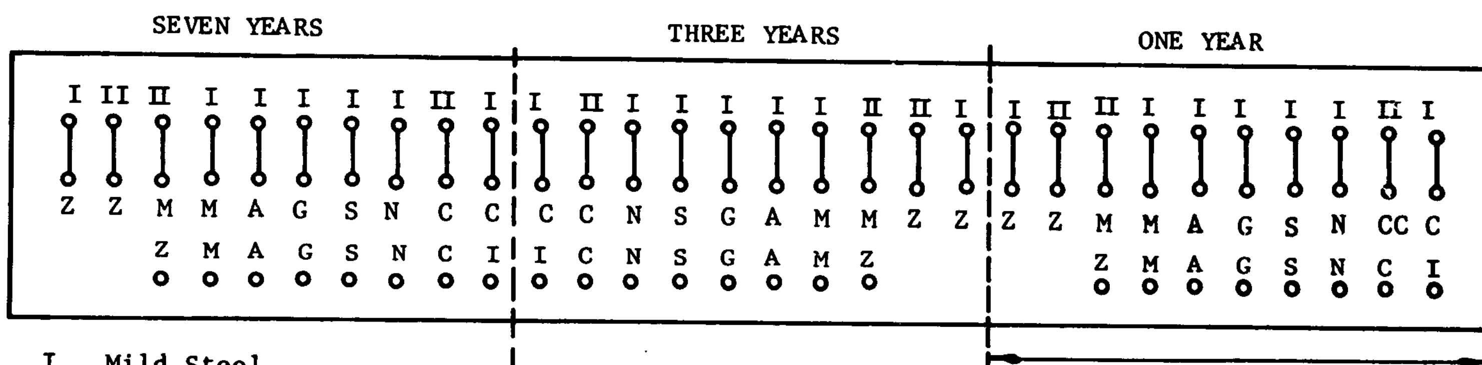


Figure 5. Typical group of ground rods. From left: mild steel, copper-clad steel, galvanized steel, zinc, Ni-Resist, stainless steel, magnesium, aluminum.



Mugu Site a Copy of This

I. Mild Steel
C. Copper-Clad Steel
N. Ni-Resist
S. Type 302 Stainless Steel
G. Galvanized Steel

A. Aluminum
M. Magnesium
Z. Zinc
II. Two Mild Steel Rods
Rods of N, A, M, and Z require pilot holes

o Single Rods
o—o Coupled Rods
Rods are on 6-foot centers

Figure 6. Arrangement of test rods.

Figure 7. Installing rods with air hammer, NCEL.

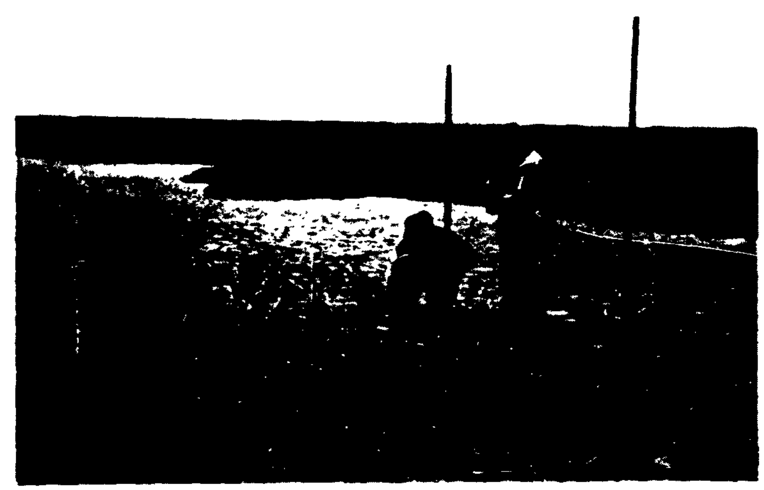


Figure 8. Installing rods with light hammer, Point Mugu.

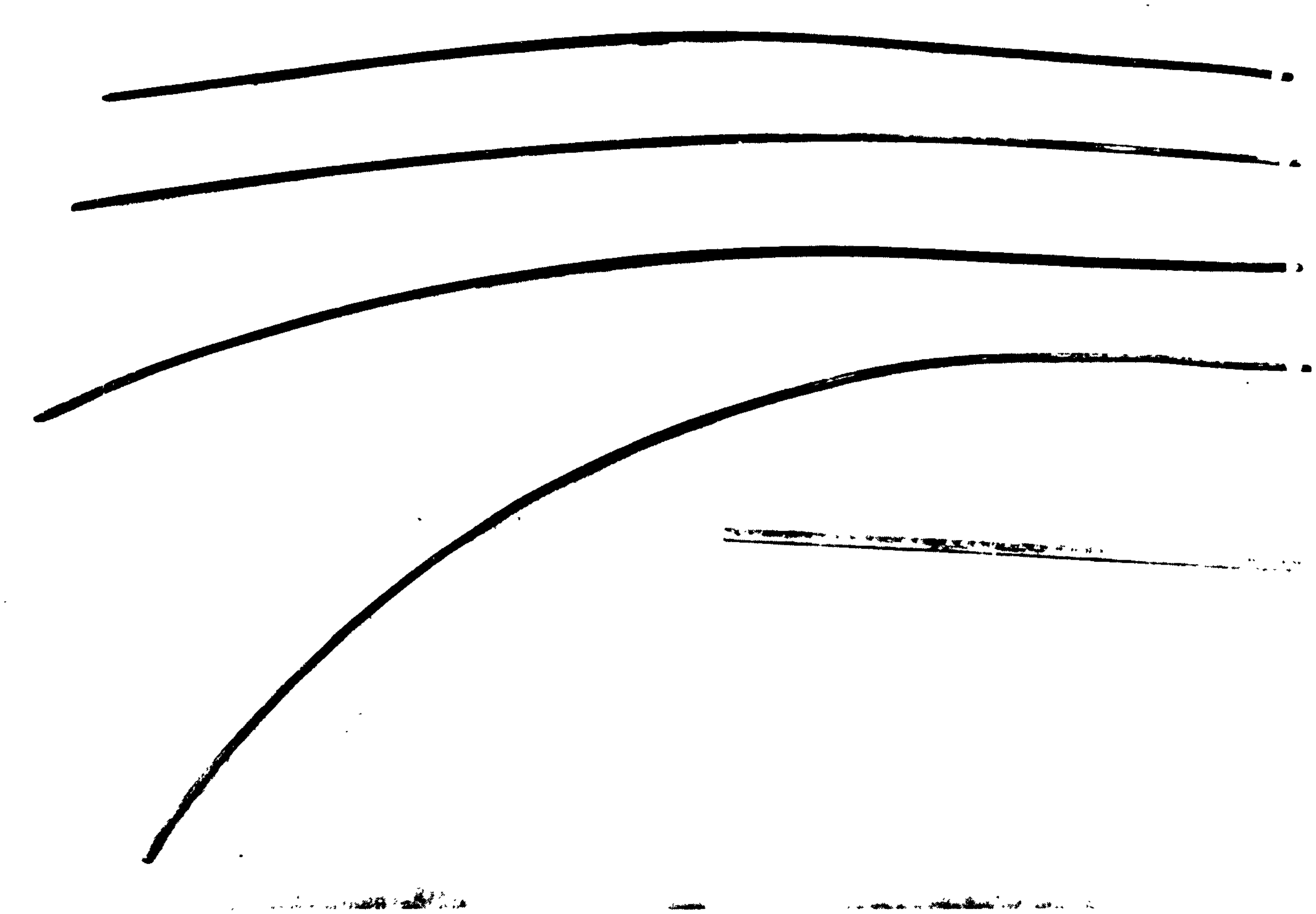


Figure 9. Bent test rods as removed from ground.

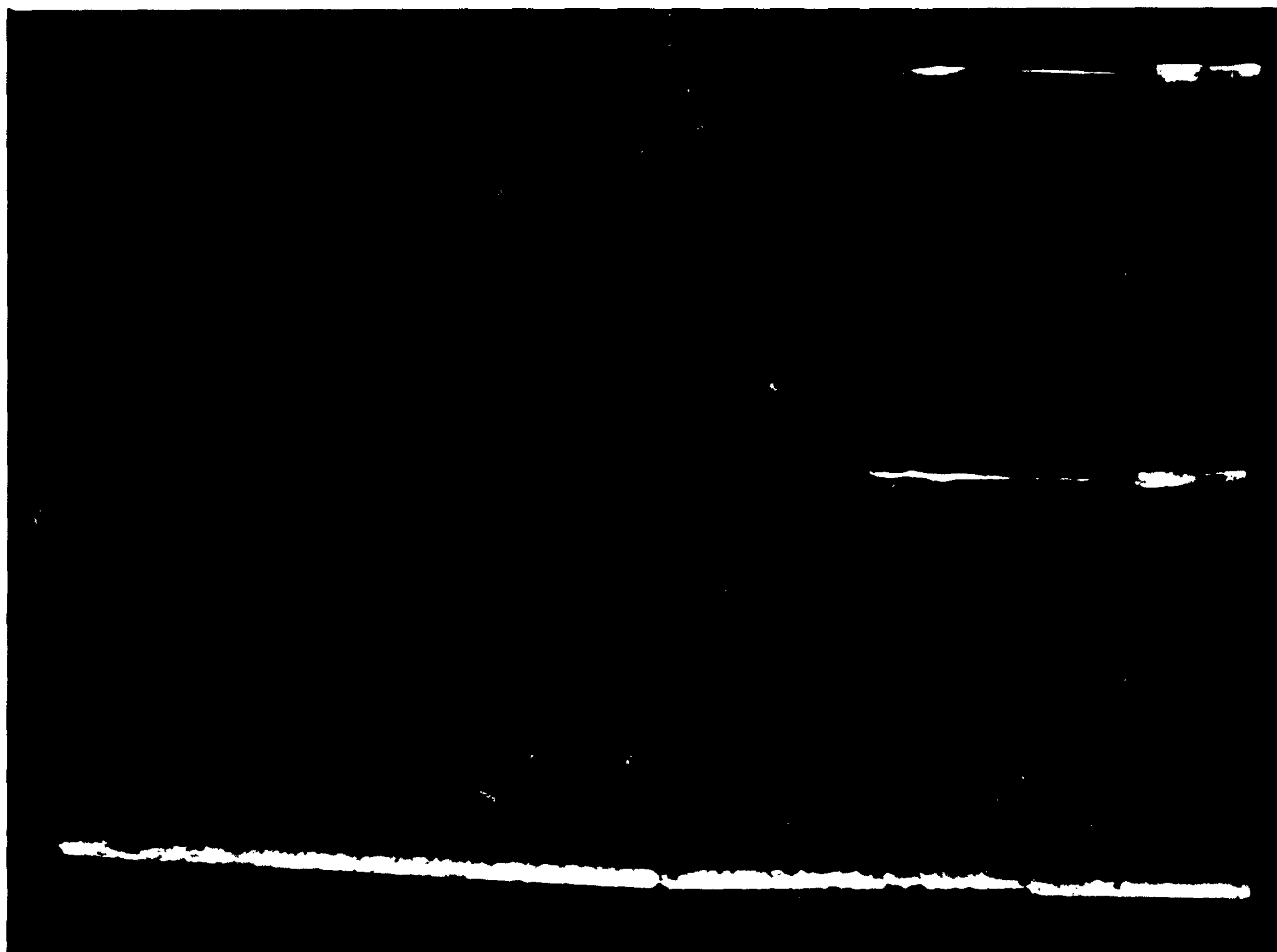


Figure 10. Remains of magnesium rods installed at Point Mugu.

APPENDIX A

Table I-A. Potential, Resistance, and Current Data for 1-Year Group of Test Rods, SCEL Site

Date	1962 2 Aug	14 Aug	31 Aug	26 Sept	25 Oct	26 Nov	19 Dec	1963 8 Jan	13 Feb	10 Apr	13 May	24 Jun	8 Aug	29 Aug
Rod	Potential to Copper Sulfate Half-Cell, Volts													
I*	-.5[illegible]	-.598	-.[illegible]18	-.599	-.596	-.587	-.597	-.587	-.631	-.706	-.625	-.622	-.635	-.658
C	-.3[illegible]	-.396	-.39	-.370	-.329	-.330	-.336	-.308	-.282	-.307	-.353	-.315	-.320	-.350
N	-.47[illegible]	-.490	-.500	-.4.2	-.501	-.488	-.495	-.481	-.532	-.518	-.530	-.521	-.567	-.590
S	-.074	-.077	-.055	-.087	-.0608	-.078	-.106	-.092	-.026	-.104	-.13	-.150	-.118	-.141
G	-1.0[illegible]	-1.045	-1.020	-1.085	-.882	-.827	-.772	-.772	-.313	-.742	-.741	-.733	-.985	-1.035
A	-.766	-.786	-.792	-.773	-.765	-.759	-.793	-.758	-.790	-.770	-.792	-.795	-.751	-.780
M	-1.545	-1.560	-1.585	-1.540	-1.540	-1.530	-1.540	-1.525	-1.535	-1.520	-1.540	-1.535	-1.545	-1.565
Z	-1.06[illegible]	-1.07[illegible]	-1.085	-1.050	-1.060	-1.055	-1.035	-1.050	-1.100	-1.060	-1.070	-1.0.5	-1.065	-1.090
I-C**	-.541	-.559	-.563	-.55[illegible]	-.542	-.537	-.550	-.537	-.542	-.537	-.553	-.545	-.593	-.642
II-C	-.540	-.545	-.558	-.554	-.548	-.546	-.565	-.551	-.584	-.538	-.560	-.558	-.617	-.651
I-N	-.528	-.525	-.552	-.540	-.538	-.520	-.550	-.532	-.567	-.557	-.570	-.590	-.637	-.659
I-S	-.51[illegible]	-.580	-.598	-.579	-.573	-.567	-.583	-.572	-.590	-.560	-.567	-.567	-.642	-.668
I-G	-.908	-.908	-.830	-.724	-.671	-.613	-.620	-.600	-.639	-.605	-.617	-.603	-.639	-.668
I-A	-.698	-.738	-.740	-.721	-.712	-.704	-.713	-.700	-.738	-.731	-.750	-.727	-.728	-.767
I-M	-1.100	-1.300	-1.335	-1.308	-1.295	-1.280	-1.290	-1.270	-1.235	-1.155	-.913	-.837	-.708	-.775
II-M	-1.16[illegible]	-1.305	-1.340	-1.315	-1.300	-1.275	-1.270	-1.245	-1.175	-1.135	-1.147	-1.070	-1.065	-1.100
II-Z	-.780	-.823	-.850	-.833	-.820	-.820	-.837	-.822	-.916	-.862	-.863	-.835	-.980	-1.035
I-Z	-.810	-.878	-.910	-.907	-.893	-.890	-.899	-.882	-.952	-.937	-.936	-.965	-.995	-1.040
	Resistance, Ohms													
I	9.[illegible]	16.0	12.1	13.1	12.0	12.[illegible]	13.1	13.0	7.4	10.5	10.8	12.2	5.1	4.6
C	10.[illegible]	11.1	10.2	11.0	11.6	12.8	12.8	13.8	9.1	11.9	12.2	12.3	2.5	1.[illegible]5
N	10.[illegible]	10.8	10.9	11.[illegible]	12.1	13.9	14.5	15.6	11.6	16.1	16.7	16.2	1.9	1.43
S	5.2	5.3	5.3	5.5	5.75	6.2	6.2	6.5	5.0	5.9	6.[illegible]	6.2	1.6	1.27
G	4.3	4.7	5.6	5.8	6.5	8.2	8.9	9.[illegible]	8.8	10.2	11.3	11.2	5.5	3.85
A	9.3	9.1	8.4	9.0	9.4	9.9	9.4	10.2	5.7	8.1	8.6	8.5	2.15	1.80
M	9.7	10.5	10.1	10.8	11.8	12.6	11.8	13.0	[illegible].6	9.4	10.2	10.1	3.0	2.35
Z	11.4	11.5	10.5	11.8	12.2	12.9	11.1	12.8	8.8	14.8	14.7	12.2	2.55	1.95
I-C	3.6	3.75	3.55	3.4	3.70	4.1	4.1	4.4	4.6	[illegible].2	5.5	5.0	1.15	1.03
II-C	3.65	3.75	3.45	3.35	3.6	3.85	3.85	4.2	3.5	5.0	5.0	4.3	1.0	.87
I-N	8.7	8.5	6.9	[illegible].3	8.0	8.9	8.9	10.0	6.2	9.3	10.6	8.9	1.27	1.25
I-S	[illegible].0	5.9	4.9	5.4	5.9	6.3	6.2	6.3	4.8	7.1	7.5	7.1	1.05	1.12
I-G	3.3	3.3	3.25	3.8	4.2	7.4	4.5	4.4	4.4	4.8	4.7	Irregular	3.05	1.03
I-A	3.15	2.8	2.65	2.6	2.75	2.9	2.95	3.05	2.6	3.25	3.35	3.2	1.07	1.23
I-M	3.10	3.0	2.75	2.5	2.7	3.15	3.15	3.3	3.05	3.45	4.0	4.2	1.85	1.90
II-M	3.75	5.2	3.3	3.35	3.6	4.1	3.75	4.1	4.0	5.5	5.5	4.3	2.55	2.35
II-Z	4.65	4.25	4.1	3.85	4.25	4.45	4.3	4.6	3.05	4.6	4.8	3.3	1.3	1.90
I-Z	4.4[illegible]	4.0	3.8	3.85	3.95	4.6	4.2	4.5	3.2	4.6	4.8	2.85	2.[illegible]	1.64
	Current, Milliamperes													
I-C	[illegible].27	10.35	11.75	11.90	10.85	11.25	9.76	9.3	Unable to take readings due to defect in current-measuring circuit in meter	8.10	9.88	10.25	11.85	10.35
II-C	[illegible].05	9.56	11.45	11.30	9.93	8.77	8.68	8.16		6.07	6.12	8.30	14.5	9.2[illegible]
I-N	1.94	2.38	3.6	2.87	2.05	1.56	1.755	1.465		1.555	1.520	1.940	2.20	3.00
I-S	1.94	1.99	2.5	2.26	2.13	1.755	1.705	1.560		1.270	1.480	1.920	1.80	1.625
I-G	28.3	25.2	21.[illegible]	15.25	11.05	7.54	6.84	6.21		4.55	4.81	5.77	3.02	4.25
I-A	10.5	10.3	14.1	10.85	10.45	9.38	8.83	8.32		5.7	6.42	7.78	11.20	11.55
I-M	58.5	55.8	64.2	51.8	55.0	48.2	46.7	44.7		30.8	18.15	16.25	10.40	9.90
II-M	[illegible]2.2	70.8	71.6	68.6	65.7	57.3	55.5	51.5		28.0	30.5	35.0	20.8	20.50
II-Z	22.[illegible]	21.0	25.3	23.5	22.8	20.8	21.8	19.05		16.05	17.10	19.35	24.8	23.0
I-Z	22.3	20.5	22.0	19.77	20.5	18.8	16.85	15.85		12.00	12.45	15.3	13.95	13.75

* Materials as Follows: I mild steel; C Copper-clad steel; N Ni-Resist; S Type 302 stainless steel; G Galvanized steel, A Aluminum alloy 6061-T6; M AZ31B magnesium alloy; Z High-purity zinc, II Two mild steel rods

**A bar between two symbols shows a couple between them

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Table II-A. Potential, Resistance, and Current Date for Rods at Mugu Site

	1962						1963						
Date	10 Aug	16 Aug	7 Sept	8 Oct	19 Nov	4 Dec	9 Jan	15 Feb	11 Apr	12 Jun	28 Jun	2 Aug	6 Sep
Rod	Potential to Copper Sulfate, Volts												
I*	-.619	-.706	-.679	-.661	-.671	-.663	-.653	-.663	-.673	-.555	-.440	-.462	-.412
C	-.480	-.580	-.490	-.461	-.548	-.531	-.506	-.470	-.554	-.453	-.510	-.405	-.502
N	-.568	-.610	-.603	-.567	-.585	-.587	-.579	-.598	-.578	-.597	-.500	-.610	-.503
S	-.316	-.290	-.308	-.218	-.260	-.268	-.147	-.250	-.240	-.120	-.202	-.182	-.106
G	-1.155	-1.155	-1.125	-1.075	-1.090	-1.075	-1.070	-1.068	-1.015	-.620	-.488	-.983	-.656
A	-.893	-.853	-.826	-.808	-.834	-.837	-.832	-.830	-.817	-.822	-.824	-.846	-.581
M	-1.630	-1.610	-1.595	-1.560	-1.580								
Z	-1.162	-1.135	-1.125	-1.080	-1.095	-1 095	-1.090	-1.110	-1.075	-1.085	-1.075	-1.090	-1.065
I-C**	-.653	-.692	-.683	-.658	-.662	-.670	-.657	-.678	-.670	-.690	-.684	-.690	-.681
II-C	-.660	-.692	-.683	-.648	-.660	-.663	-.664	-.680	-.650	-.675	-.681	-.675	-.680
I-N	-.636	-.690	-.697	-.665	-.675	-.678	-.661	-.675	-.662	-.687	-.680	-.680	-.670
I-S	-.654	-.695	-.699	-.670	-.678	-.681	-.673	-.678	-.670	-.685	-.691	-.683	-.787
I-G	-1.095	-1.125	-1.110	-1.000	-.875	-.795	-.723	-.768	-.710	-.717	-.713	-.738	-.738
I-A	-.821	-.838	-.823	-.810	-.825	-.833	-.833	-.827	-.815	-.844	-.813	-.836	-.782
I-M	-1.420	-1.465	-1.305	(3)									
II-M	-1.370	-1.455	-1.280	(3)									
II-Z	-1.087	-1.110	-1.100	-1.060	-1.080	-1.085	-1.075	-1.100	-1.050	-.807	-1.060	-1.075	-1.060
I-Z	-1.110	-1.120	-1.105	-1.065	-1.085	-1.092	-1.080	-1.105	-1.060	-1.080	-1.065	-1.080	-1.065
	Resistance, Ohms												
I	0.53	.52	.55	.56	.39	.70	.37	.54	Unable obtain readings due to defect in circuit which could not be located	10.50	6.5	2-6 (1)	.72
C	.56	.52	.48	.50	.44	.50	.36	.47		0.37	.34	.62	.63
N	.58	.56	.62	.53	.37	.59	.35	.59		0.42	.41	.55	.47
S	.70	.51	.64	.55	.42	.61	.41	.69		0.44	.34	.49	.49
G	0.72	.58	.63	.92	.84	.68	.67	.79		95(1)	30.1	.63	1.12
A	.69	.57	.60	.60	.49	.61	.49	.62		0.49	.41	3-4	.55
M	.63	.66	.84	.84	29.0 (2)								
Z	.61	.50	.64	.78	.98	.89	.72	.81		4.5	3.0	1.27	.91
I-C	.43	.40	.55	.43	.29	.42	26	.35		.42	.23	.40	.38
II-C	.39	.37	.50	.41	.27	.39	.26	.31		.47	.22	.45	.49
I-N	.42	.44	.46	.42	.57	.55	.26	.54		.78	.27	3.0	.63
I-S	.43	.48	.47	.43	.29	.44	.27	.41		.30	.18	.60	.42
I-G	.42	.45	.47	.52	.47	.63	.56	.55		22.0	1.5(1)	28.(1)	28.(1)
I-A	.48	.47	.47	.44	.32	.48	.29	.31		0.33	1.4	.7	.68
I-M	.46	.43	.68										
II-M	44	.38	.56										
II-Z	38	.36	.50	.48	.38	.52	.36	.36		3.3	.48	.57	.67
I-Z	44	.44	.77	53	.47	.60	.59	.58		1.25	.47	.68	.75
	Current, Milliamperes												
I-C	4.08	4.1	4.62	1.94	1.80	1.56	2.47	1.245	0.39	0.40	.31	.24	.34
II-C	3.50	4.8	6.68	5.73	3.12	5.56	1.525	1.250	2.75	1.52	1.010	1.32	.32
I-N	4.06	3.05	2.0	1.00	.630	.515	.655	.535	.800	.335	.340	.340	.29
I-S	0.94	1.6	2.02	.425	.220	.225	.710	.500	.485	.365	.120	.090	.105
I-G	47.0	28.2	9.1	3.80	.795	.460	1.010	.620	.490	.470	.415	2.05	1.15
I-A	5.5	3.63	5.21	.4.42	1.815	2.22	1.180	.48	1.125		.515	.510	.405
I-M	.605	1.12	.470										
II-M	.789	1.12	.420										
II-z	62.7	66.5	16.5	8.27	5.30	7.95	6.60	4.59	9.75	4.33	10.4	5.80	4.70
I-Z	49.3	34.0	11.0	6.35	3.44	4.73	4.07	2.36	5.63	2.04	3.65	3.30	1.76

*Materials as Follows: I=Mild steel; C= Copper-clad steel; N= Ni-Resist; S= Stainless (302) steel; G= Galvanized steel,
A= Aluminum; M= Magnesium, Z= Zinc,
II= Two mild steel rods

**A bar between two symbols indicates a couple made between them

(1) Varying
(2) Corroded through 2½" below ground, 4 months after installation.
(3) In place for 8 weeks only.

Table III-A. Weight Changes and Corrosion Rates of Ground Rods Driven in Two Locations

Rod Number	Material (1)	Use of Rods	NCEL Site: Weight, Original (Gms)	NCEL Site: Weight, Loss (Gms)	NCEL Site: Weight, %Loss	NCEL Site: Corrosion Rate, Gm/SqCm/Yr	Mugu Site: Weight, Original (Gms)	Mugu Site: Weight, Loss (Gms)	Mugu Site: Weight, % Loss	Mugu Site: Corrosion Rate, Gm/SqCm/Yr
1	I	Single	3751	96	2.56	.0736	3776	52	1.37	.0396
2	G	"	3629	56	1.54	.0435	3662	90	2.46	.0699
3	C	"	3449	18	.52	.0147	3381	19	.56	.0155
4	N	"	3819	26	.68	.0195	3560	14	.39	.0114
5	S	"	3822	7	.18	.0053	3803	2	.053	.0015
6	I	Coupled to No. 9	3749	181	4.83	.138	3776	65	1.72	.0498
7	I	Coupled to No. 10	3754	90	2.41	.0642	3777	86	2.28	.0657
8	I	Coupled to No. 11	3752	95	2.53	.0727	3775	76	2.01	.0581
9	C	Coupled to No. 6	3442	13	.38	.0106	3392	6	.18	.0049
10	N	Coupled to No. 7	3814	10	.26	.0073	3557	4	.11	.0030
11	S	Coupled to No. 8	3832	2	.052	.0015	3811	2	.053	.0015
12	A	Single	1303	12	.92	.0091	1306	4	.31	.0031
13	M	"	857	54	6.31	.0412	852	630 (4)	73.9	.481
14	Z	"	3416	41	1.20	.0314	3412	40	1.17	.0306
15	I	Coupled to No. 18	3743	38	1.02	.0291	3771	37	.98	.0282
16	I	Coupled to No. 19	3748	32	.85	.0244	3768	32 (3)	.85	.0244
17	I	Coupled to No. 20	3748	46	1.22	.0351	3782	33	.87	.0252
18	A	Coupled to No. 15	1307	96	7.35	.0734	1340	20	1.49	.0153
19	M	Coupled to No. 16	849	474 (5)	55.8	.344	852	820 (3)	96.2	.626
20	G	Coupled to No. 17	3713	138	3.72	.105	3619	94	2.60	.0737
21	I	Coupled to No. 27	3764	144	3.83	.110	3769	70	1.85	.0536
22	I		3757	134	3.57	.103	3775	86	2.28	.0660
23	I	Coupled to No. 28	3746	30	.80	.0230	3781	31 (3)	.82	.0237
24	I		3752	33	.88	.0252	3768	29 (3)	.72	.0221
25	I	Coupled to No. 29	3743	33	.89	.0252	3782	61	1.61	.0465
26	I		3751	27	.72	.0206	3785	37	.98	.0282
27	C	Coupled to No's. 21, 22	3461	12	.35	.0097	3393	5	.15	.0041
28	M	Coupled to No's. 23, 24	856	592 (5)	69.2	.452	847	821 (3)	96.9	.626
29	Z	Coupled to No's. 25, 26	3413	284	8.32	.217	3415	161	4.72	.123
30	Z	Coupled to No's. 91/31 (2)	3415	235	6.88	.179	3419	105	3.07	.0805
91/31	I	Coupled to No. 30	3749	33	.88	.0252	3781	29	.72	.0231

(1) Materials as Follows: I= Mild steel; G= Galvanized steel; C= Copper-clad steel; N= Ni-Resist; S= Stainless (302) steel; A= Aluminum; M= Magnesium; Z= Zinc

(2) No. 31 installed at Point Mugu

(3) In place for 8 weeks only

(4) In place for 4 months

(5) Includes uncorroded metal in corrosion product

APPENDIX B

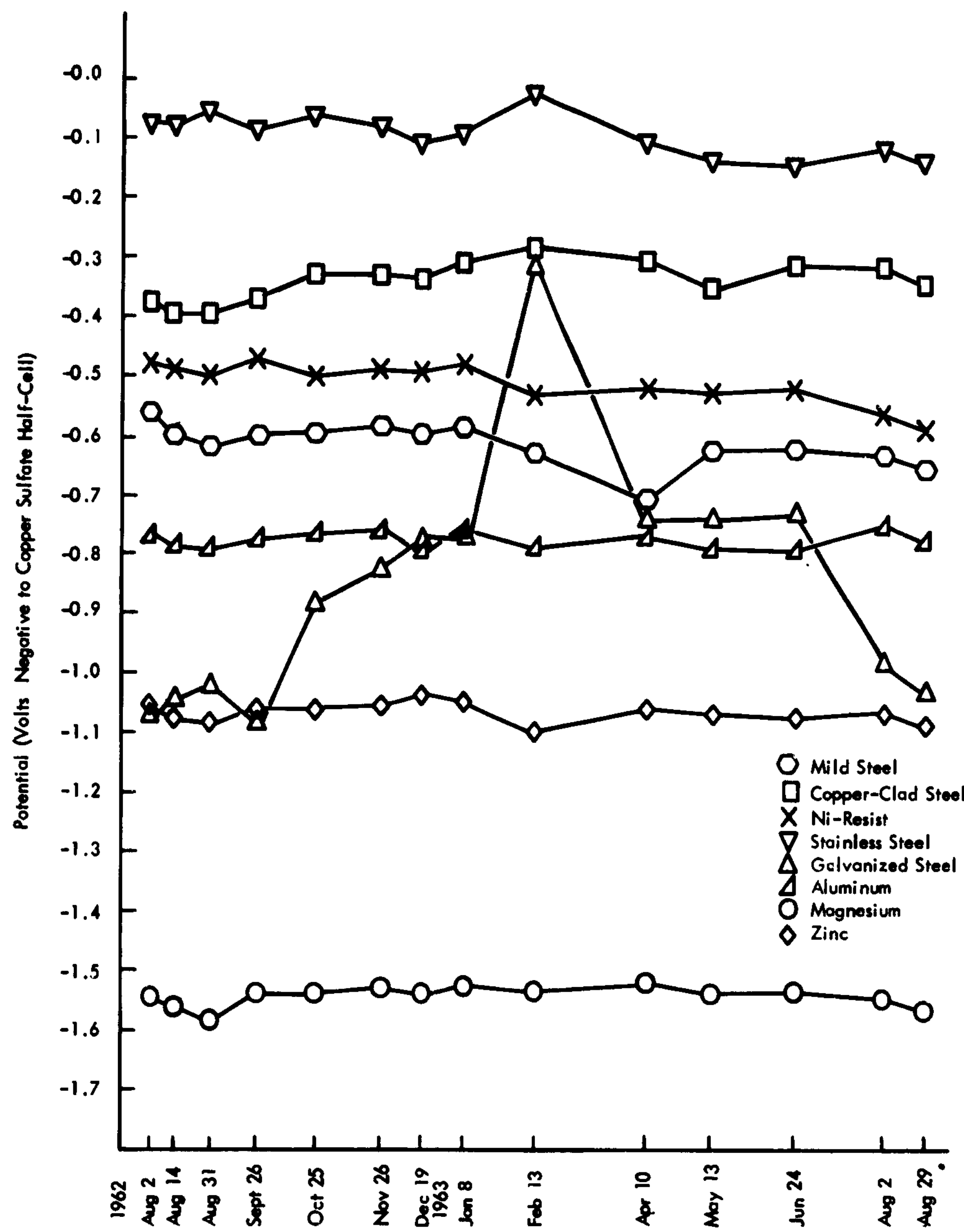

Figure 1-B. Potential of Single Rods.
NCEL Site 1 year Group.

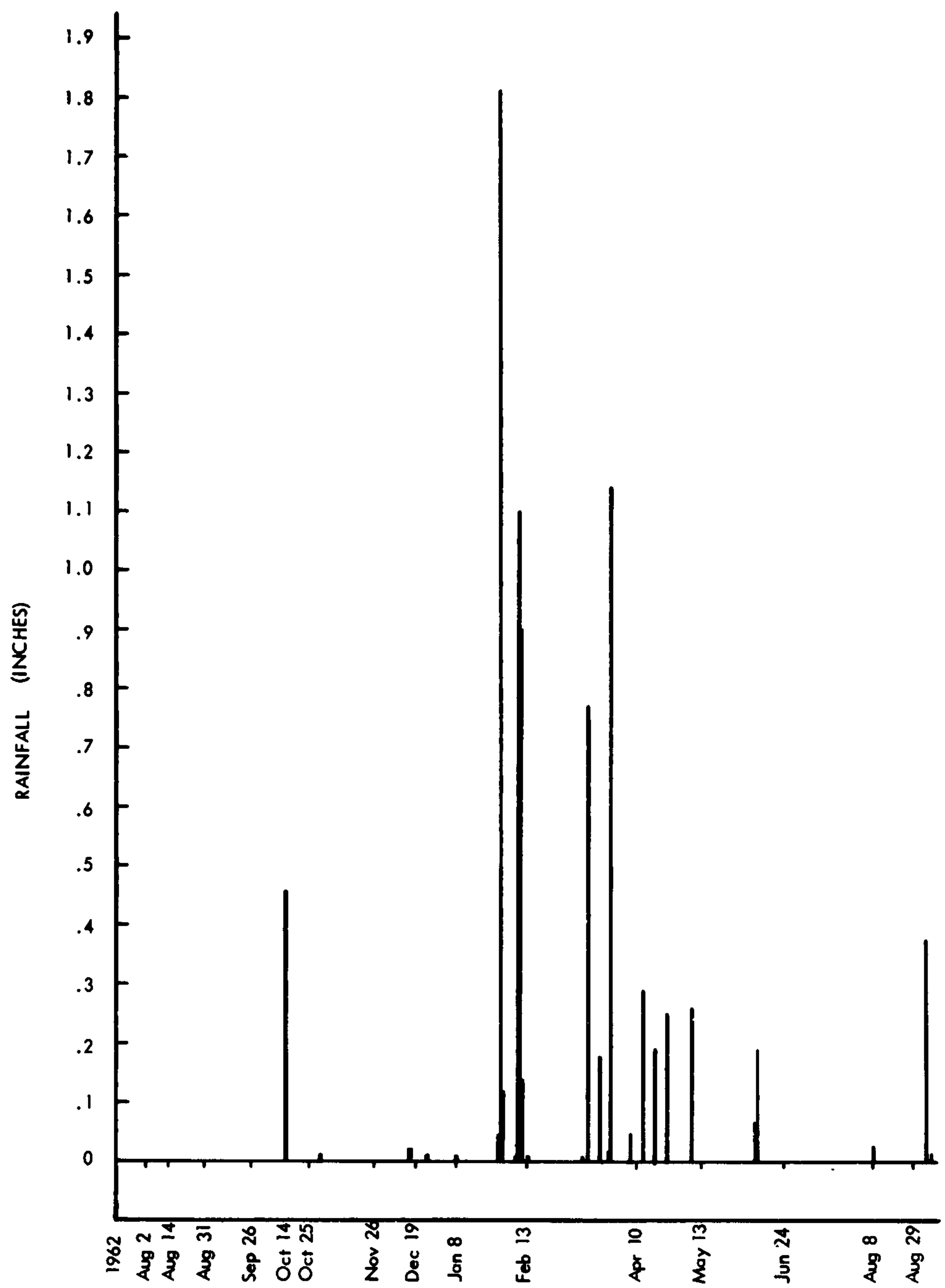

Figure 2-B. Rainfall During Test Period.

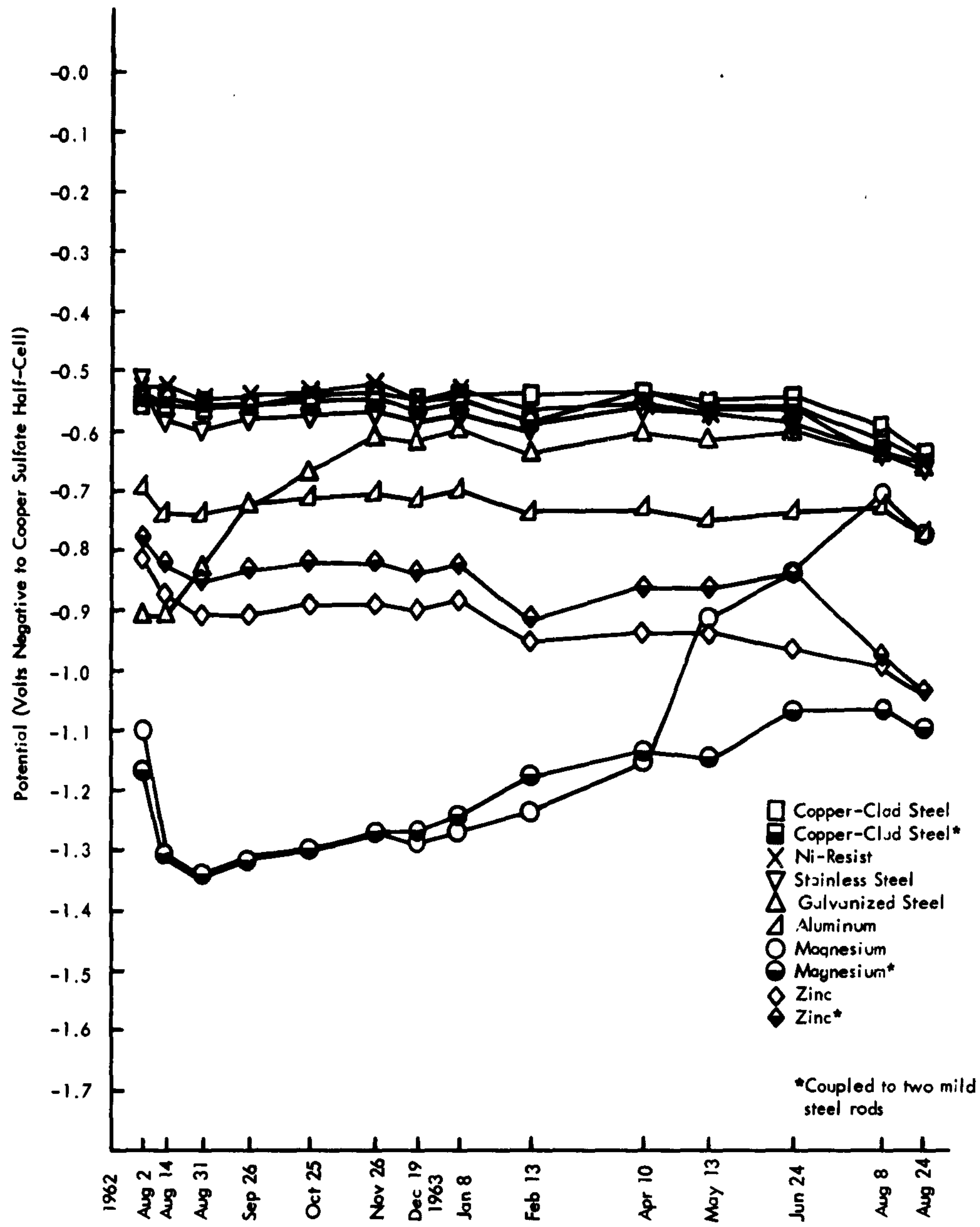

Figure 3-B. Potential of Coupled Rods.
NCEL Site - 1 Year Group.

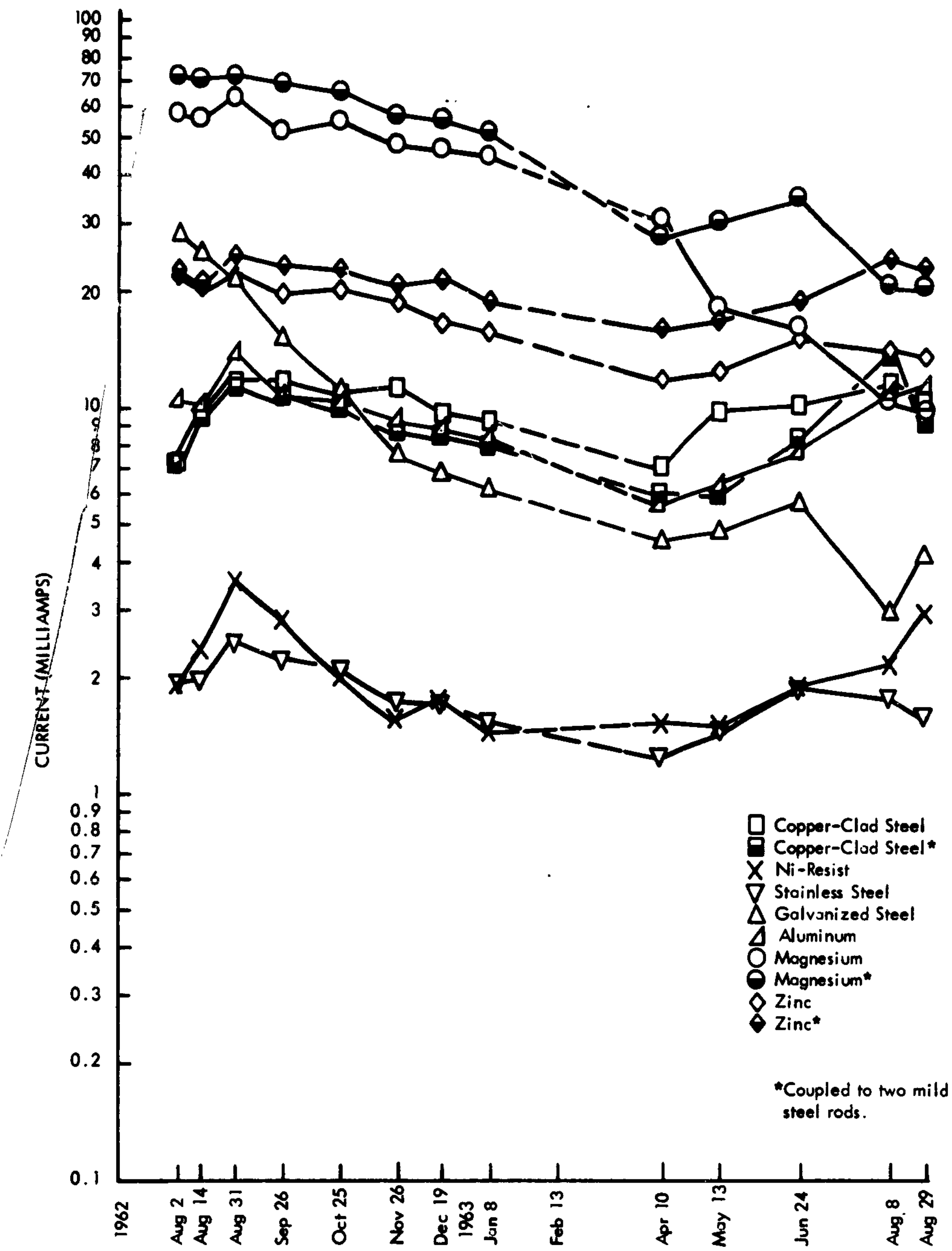

Figure 4-B. Current Flow in Couples.
NCEL Site - 1 Year Group.

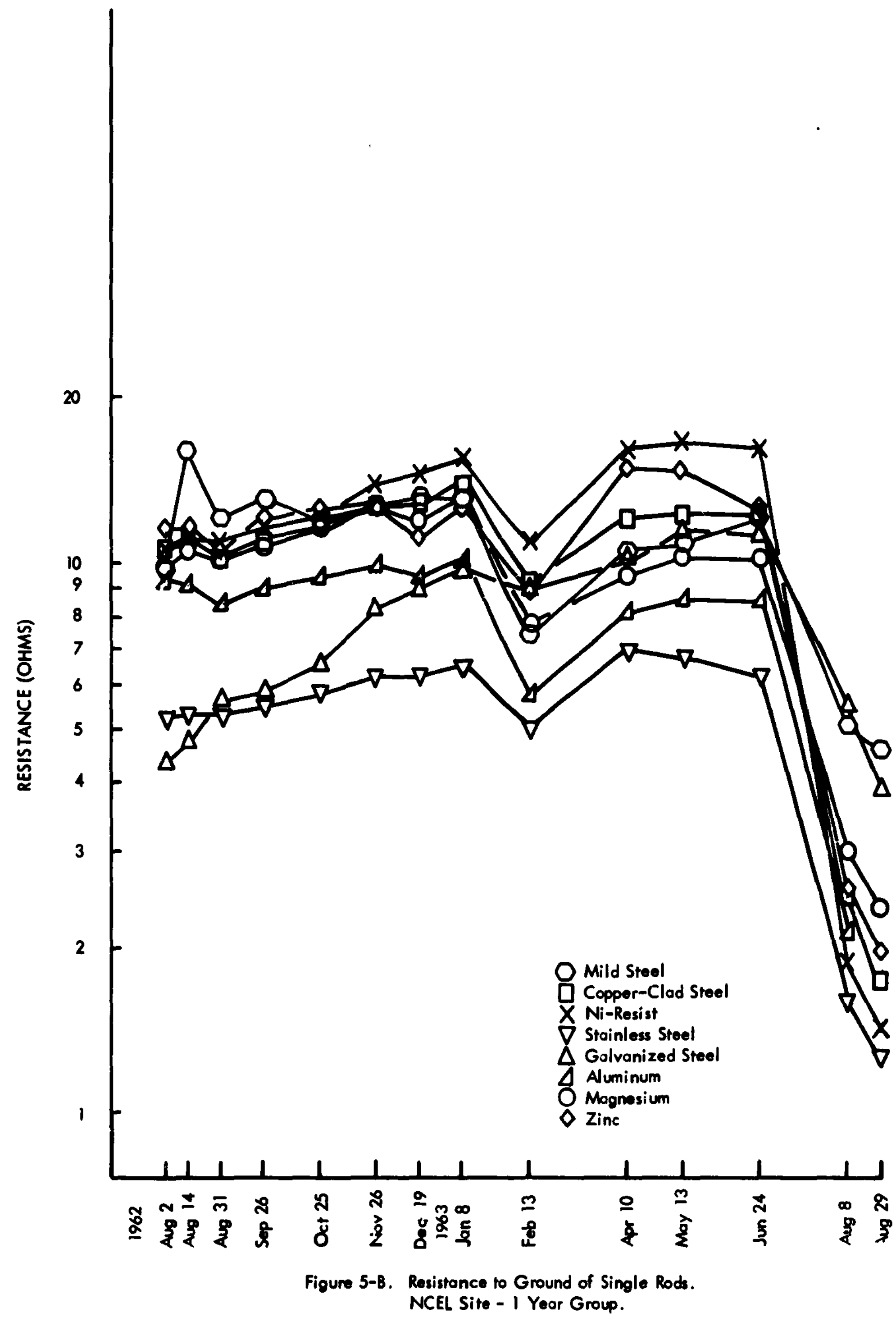

Figure 5-B. Resistance to Ground of Single Rods.
NCEL Site - 1 Year Group.

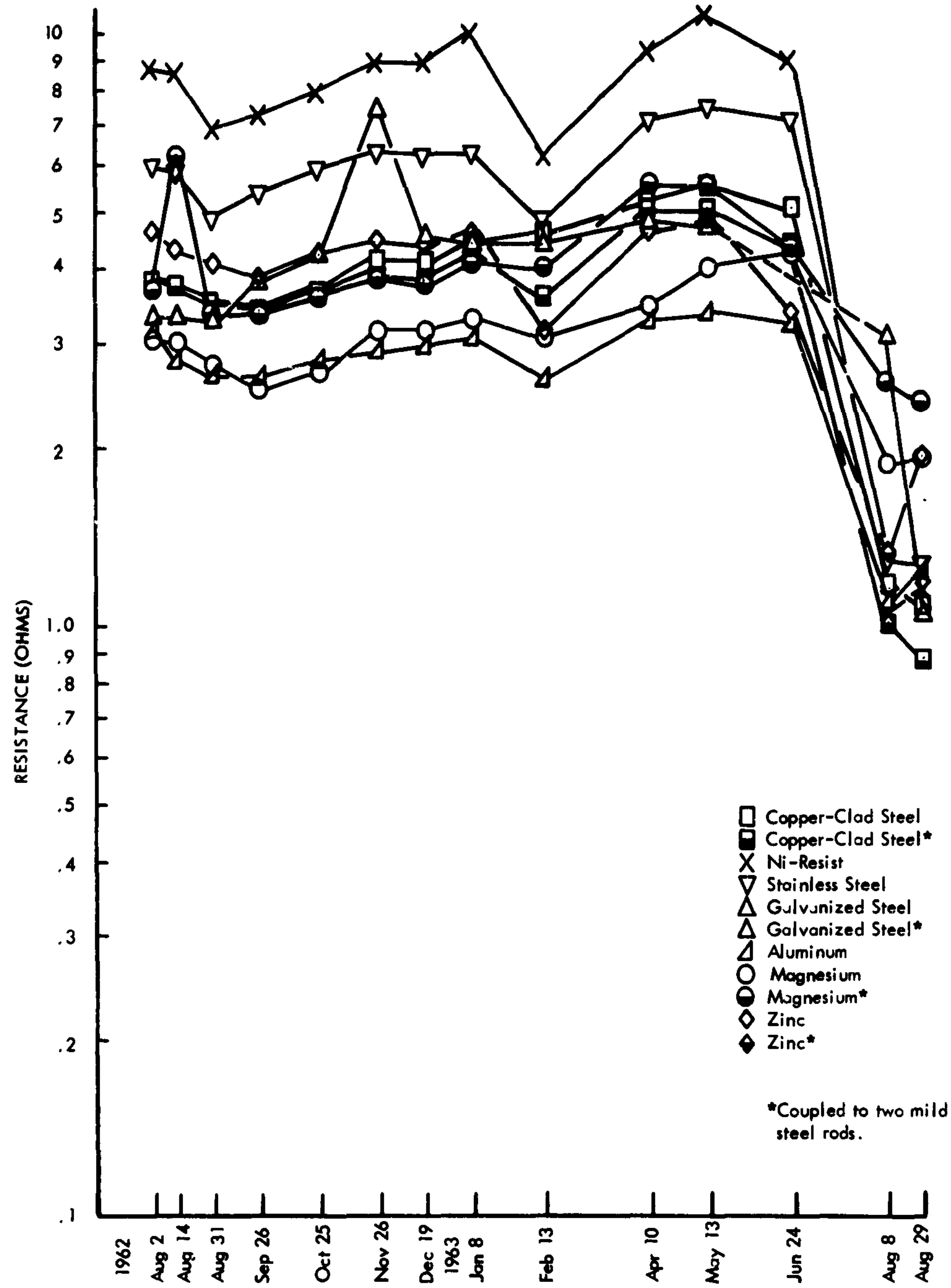

Figure 6-B. Resistance to Ground Rod of Coupled Rods.
NCEL Site

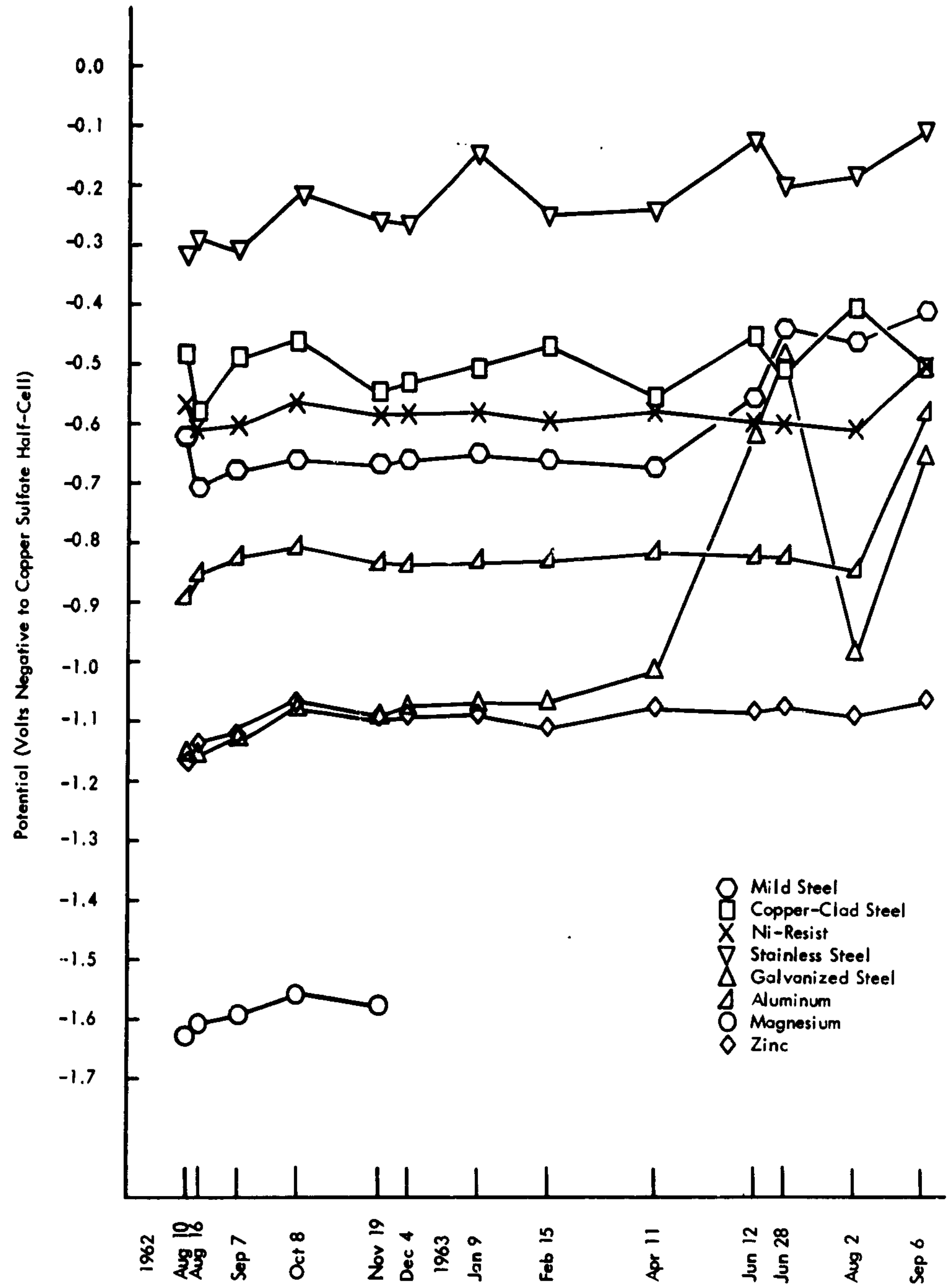

Figure 7-8. Potential of Single Rods.
Mugu Site

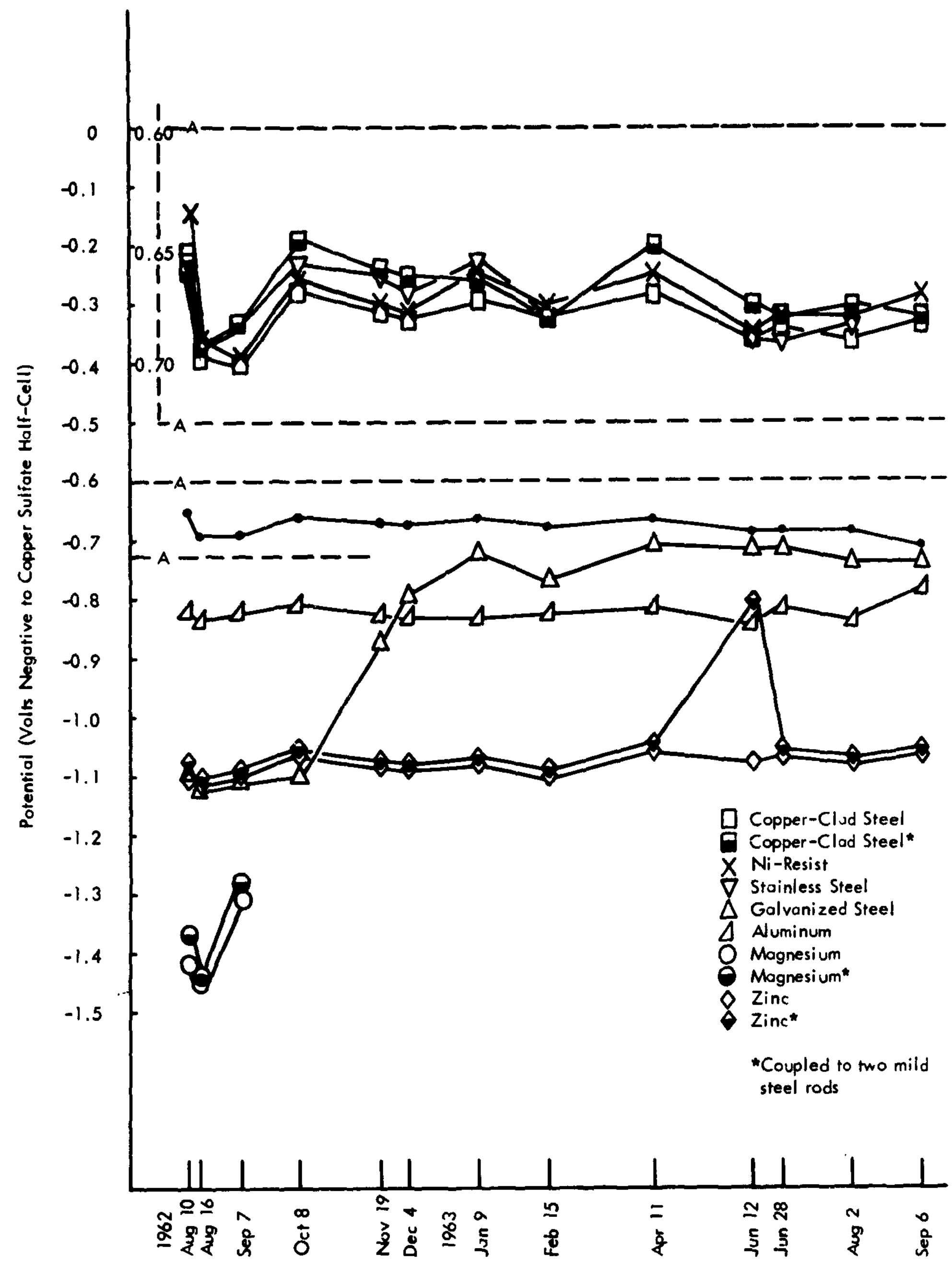

Figure 8-8. Potential of Coupled Rods.
Mugu Site

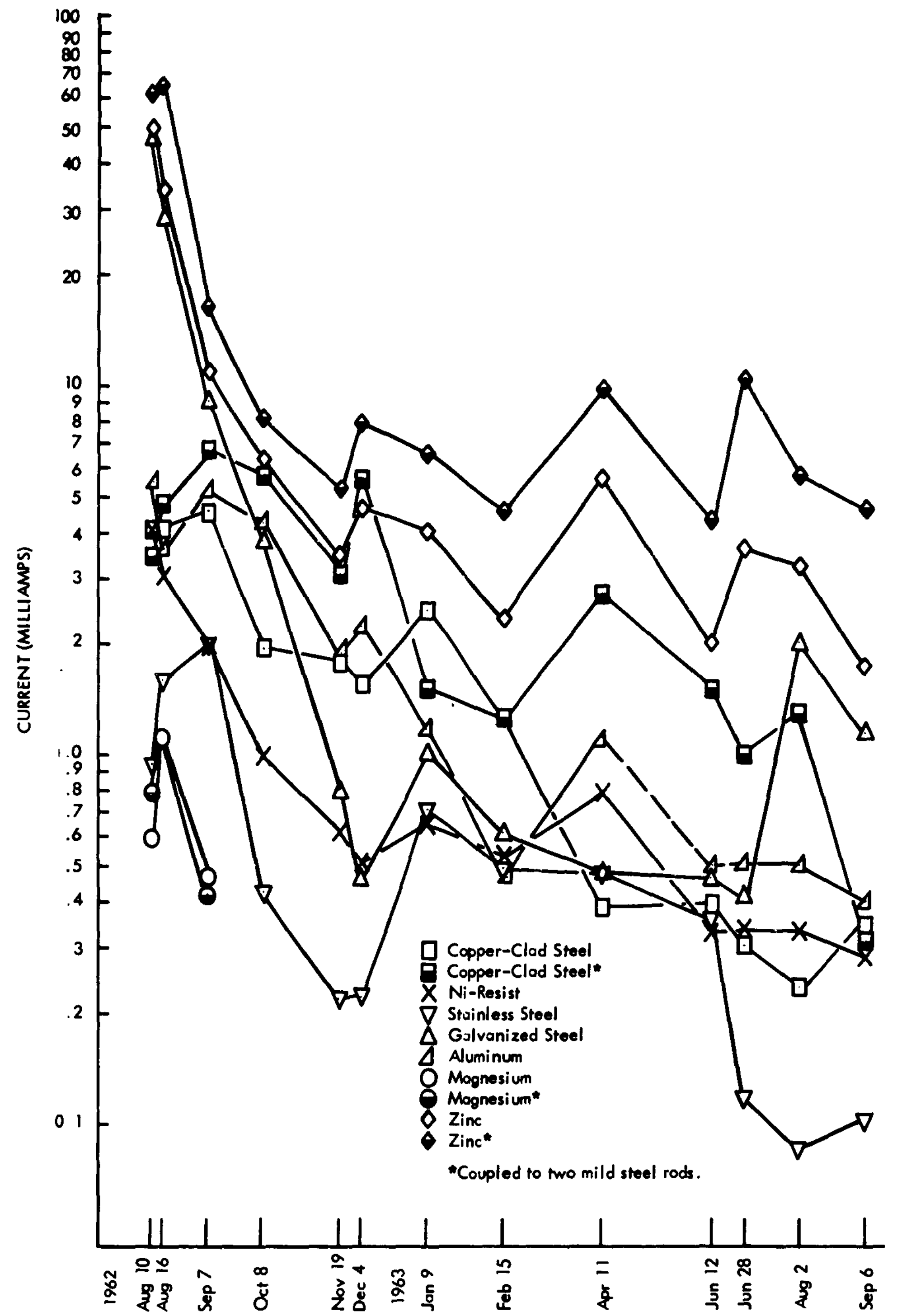

Figure 9-B. Current Flow in Couples.
Mugu Site

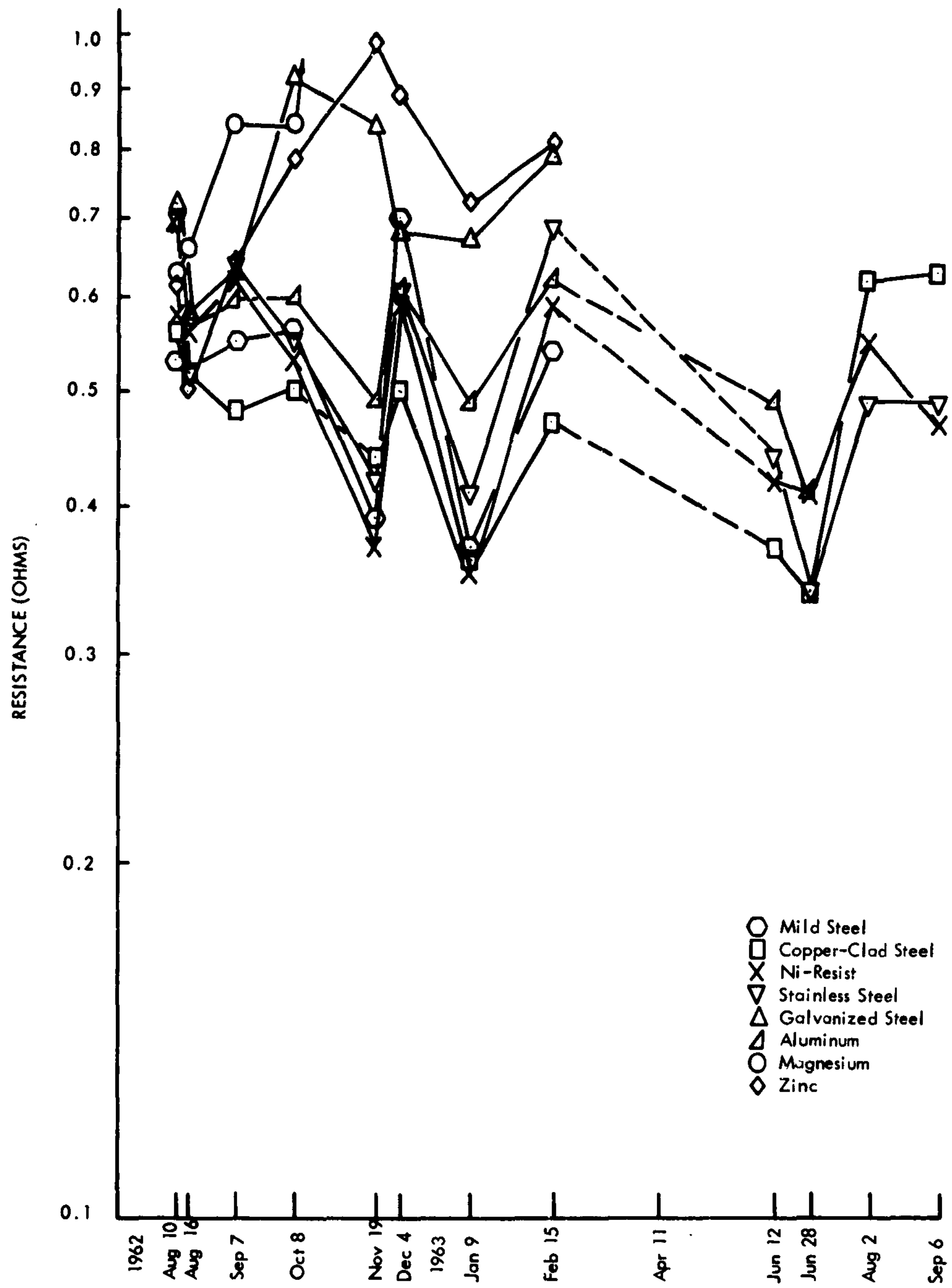

Figure 10-B. Resistance to Ground Rods of Single Rods.
Mugu Site

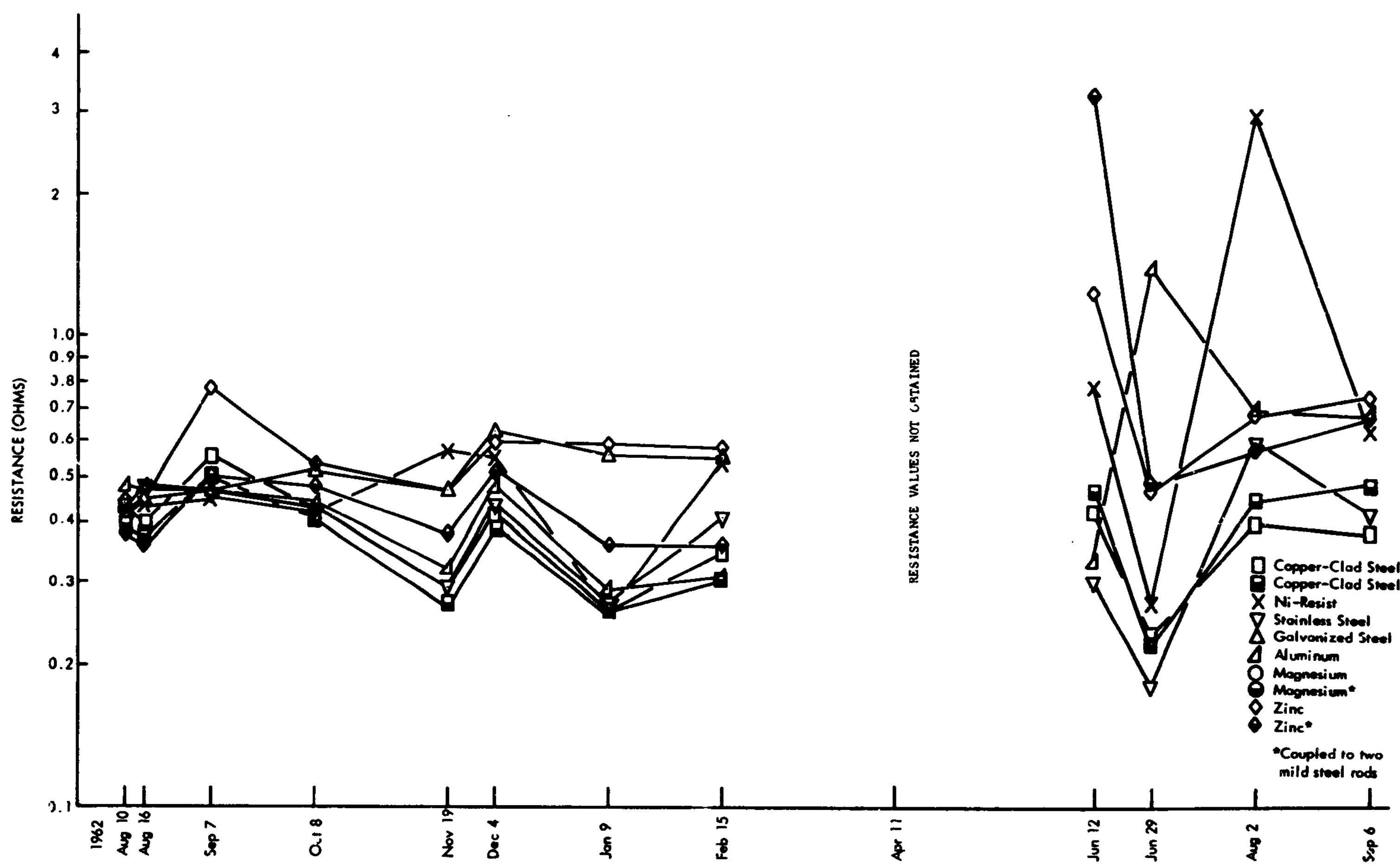

Figure 11-B. Resistance to Ground Coupled Rods.
Muru Site

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1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval Civil Engineering Laboratory, Port Hueneme, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED; 2b. GROUP

3. REPORT TITLE

GROUND ROD METALS - RESULTS OF TWO ONE-YEAR TESTS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim 2 August 1962 - 2 September 1963

5. AUTHOR(S) *(Last name, first name, initial)*

Hanna, Alfred E.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 October 1964	40	4

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) TN N-633
b. PROJECT NO. Y-F015-99-01-031	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

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13. ABSTRACT

The U. S. Naval Civil Engineering Laboratory has been investigating various metals now in use as ground rods, and metals which might be acceptable substitutes. NCEL cooperated with the National Association of Corrosion Engineers by installing a series of test rods at the Laboratory. A smaller set was installed at the Naval Air Station, Point Mugu, California as a short-term test. Test results are given for the first group of rods from the NCEL site and for the set from Point Mugu. It is recommended that corrosion-resistant iron alloys be authorized for use in grounding systems.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
metals	8					
corrosion resistant steels	8					
iron alloys	8					
grounding (electrical)	4					

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